GEOLOGY AND MINERALIZATION OF THE ROSEBERY- HERCULES AREA, TASMANIA.

Clarke by
Terry C. Lees, B. App. Sci. (Geol.)

submitted in fulfilment of the requirements
for the degree of Master of Science.

UNIVERSITY OF TASMANIA

HOBART
1987

Except as stated herein, this thesis contains no material which has been accepted for the award of any other degree or diploma in any university, and that, to the best of my knowledge and belief, this thesis contains no copy or paraphrase of material previously published or written by another person, except when due reference is made in the text of the thesis.

Terry Lees
March, 1987

CONTENTS

FIGURES

TABLES

PLANS

APPENDICES

ABSTRACT

The sequence hosting the Rosebery and Hercules orebodies is interpreted as a caldera complex. The felsic "footwall pyroclastics" represent caldera-forming ash-flow tuffs, in part deposited subaerially. Collapse of the caldera led to deposition of tuffaceous sediments over much of the area, and triggered formation of the massive sulphide deposits. A series of quartz-bearing mass flows interrupted the ensuing quiet sedimentary regime, but rapid and systematic variations in thickness of this sequence indicate resurgence of the caldera. The Mt. Black Volcanics, of massive dacitic, andesitic and minor basaltic lavas, with subordinate tuffs and limestone, were erupted during renewed volcanism.

Overlying the "central sequence" volcanics unconformably is the White Spur Formation at the base of the Dundas Group. This is composed of epiclastic mass flows with an increasing sedimentary component, culminating in the argillaceous Chamberlain Shale, which is followed by Stitt Quartzite, dolomitic Westcott Argillite, and interfingering Natone Volcanics and Salisbury Conglomerate.

The Rosebery Fault is a major thrust, with a down-dip displacement of at least 1.5 km, which juxtaposes White Spur Formation with "footwall pyroclastics" west of Rosebery. The Dundas Group west of the fault is disrupted by faults and tectonic melange zones.

Rosebery is a well-documented stratiform massive sulphide deposit. Footwall to ore is often strongly altered "quartz schist", but a chlorite-chalcopyrite-pyrite-magnetite stringer zone has recently been located beneath F lens. The ore lenses typically consist of basal massive pyrite-chalcopyrite directly overlain by banded pyrite-galena-sphalerite ore, and a separate, stratigraphically higher barite-sulphide lens. In F lens, barite occurs at the top of the pyrite - galena - sphalerite ore. Replacive tourmaline - pyrite - pyrrhotite - magnetite assemblages appear to be related to ?Devonian granite metasomatism.

The smaller Hercules orebody consists of a number of discrete but adjacent lenses oriented parallel to regional cleavage. The lenses show zonation from chalcopyrite-pyrite stringers at the base, to massive chalcopyrite - pyrite, then massive galena - sphalerite ore. Textures of the ore are often porphyroblastic, but primary features of "spotty ore" at the extremitites and below massive sulphide lenses, indicate a cavity - filling or replacement origin for some of the sulphides. The ore lenses are interpreted as a deformed massive sulphide orebody. Spheroidal carbonates are closely associated with ore and represent strong carbonatization of original tuff. Precious metal mineralization at South Hercules has unusual textures, distribution, mineralogy and relationships with carbonate alteration that suggest a replacement origin.

1 INTRODUCTION

1.1 AIMS

In April 1982, the Electrolytic Zinc Co. (E.Z.) commenced a project aimed at exploring the Read-Rosebery mine lease and adjacent areas, shown in Fig. 1, for further ore reserves. As an adjunct to this work, this thesis was initiated during 1984, to study the volcanic, volcano-sedimentary and sedimentary sequences in the area; their structure, relationships and origins; the geology and genesis of various mineralization styles present; and the relationship between geology and mineralization.

As the Rosebery deposit is described in detail elsewhere, (Brathwaite, 1974; Green, 1983; Naschwitz, 1985) it is only discussed briefly, but some new information and interpretations are presented. The Hercules deposit has been documented only briefly by Hall (1967), and Fitzgerald (1974), and it is discussed in some detail.

1.2 PHYSIOGRAPHY VEGETATION AND CLIMATE

The Rosebery-Hercules area comprises densely forested rugged terrain typical of the West Coast of Tasmania. Present physiography is largely a result of Quaternary-Recent glaciation. Mt. Read (1,122m.) in the SE part of the project area is the highest point on an alpine plateau that extends across to Mt. Hamilton (1,007m) above the Hercules mine. As the ridges and creeks descend northwards toward Rosebery, the effect of glacial deposition becomes apparent - ridges commonly have a veneer of till, while creeks have thicker cover. Valleys of the larger streams (Pieman River and Stitt River) have extensive buttongrass plains developed on glacial till but since the glaciation the rivers have eroded through to bedrock. Mt. Black (929m), above the township of Rosebery, is separated from the main West Coast Range by the valleys of the Stirling and Stitt Rivers, and has been glaciated.

The Mt. Read - Mt. Hamilton plateau has a cover of alpine rainforest, moorland and shrubbery. Thick alpine rainforest consists of conifers such as King Billy and Pencil Pine, <u>Anthrotaxis spp.</u>, the Chestnut Pine <u>Diselma archeri</u>, with deciduous beech <u>Nothofagus gunnii</u>, also <u>Pandanus</u>, <u>Scoparia</u> and <u>Richea</u> species. Mountain shrubberies contain a diverse alpine flora.

Temperate rainforest covers moist slopes and valleys, ascending to mountains where it may occur as stunted trees mingling with alpine flora. The rainforest is dominated by myrtle <u>Nothofagus cunninghamii</u> with a variety of other species notably leatherwood <u>Eucryphia lucidia</u>, horizontal <u>Andalopetalum biglandolusum</u>, and blackwood, <u>Acacia melanoxylon</u>.

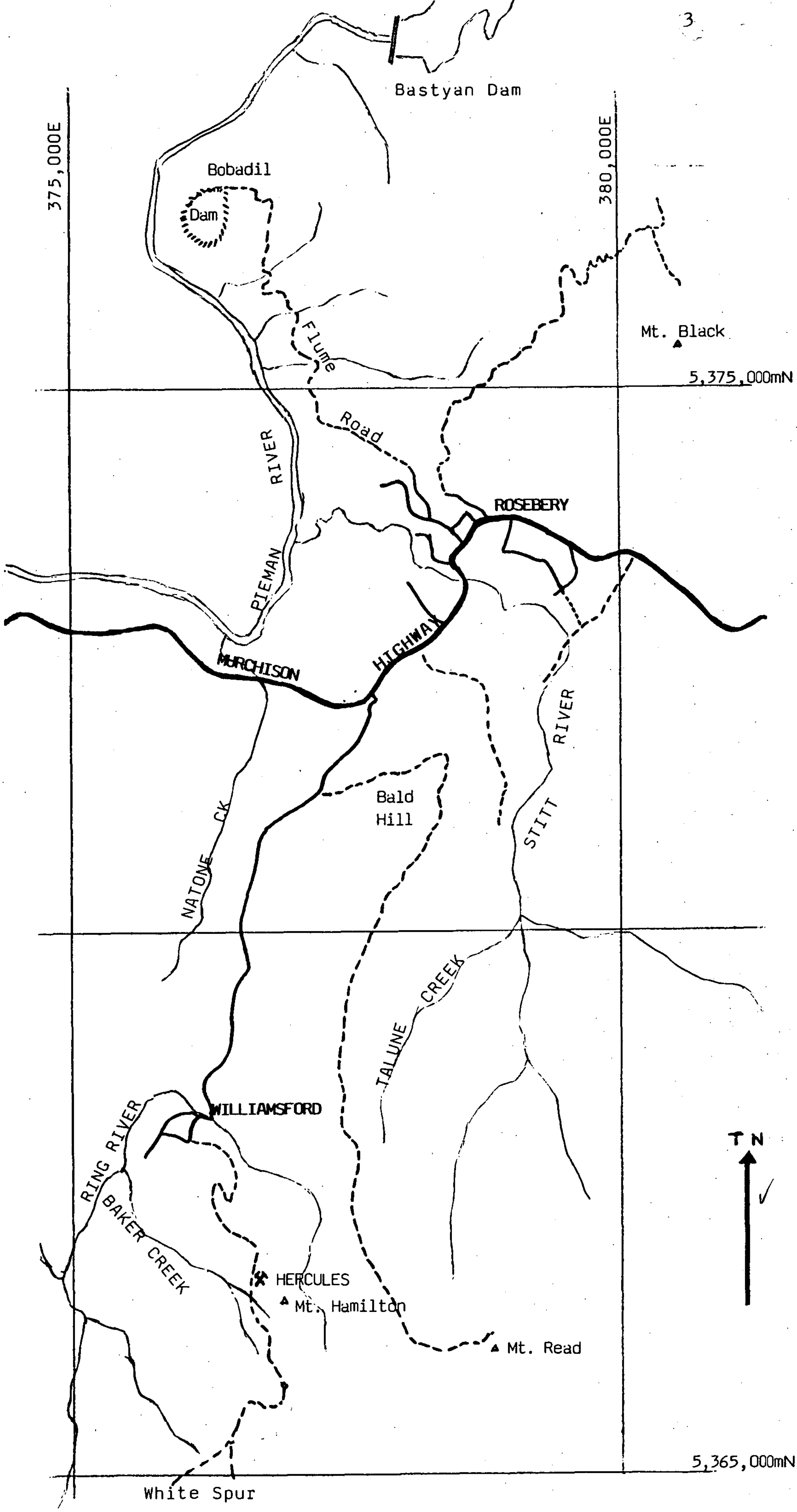


FIGURE 1. - Project Area - Rosebery, Western Tasmania
(Scale 1:50,000) √

The tree fern, Dicksonia antartica is common in damp gullies, with many other ferns.

Wet scherophyll forest occupies the more prominent ridges, with tall gums Eucalyptus obligua and E. regrans dominant. The understory is composed of rainforest species, wattles, and other such as the impenetrable bauera, Bauera ruboides.

Sedgeland usually develops on poor soils especially glacial till. Buttongrass, Gymnoschoenus sphaerocephalus, predominates.

Fires have a major effect on vegetation, as rainforest in particular takes many years to regenerate. A number of species such as tea-tree, Leptospermum scoparium and bottlebrush, Melaleuca spp. take advantage of fire by rapidly occupying the vacant niche. The climate is cold and wet; Rosebery's average rainfall is 2612mm (85") per annum. Precipitation at Williamsford and Hercules is probably significantly higher. Snowfalls are common in the highlands in winter.

1.3 PREVIOUS LITERATURE

In an abundance of literature on aspects of the geology of the Rosebery area, the works of Brathwaite (1969), Green et al. (1981) and Green (1983) stand out. Brathwaite (1969) established Rosebery as a volcanic-associated stratiform massive sulphide deposit, and followed his thesis with papers on the structure (Brathwaite, 1972) and origin (Brathwaite, 1974) of the deposit. Green et al. (1981) provide a detailed model of ore genesis, while Green's (1983) thesis describes the regional geology and details the isotope characteristics, metal zoning and method of formation of the Rosebery ore deposit.

Other workers concentrating on the Rosebery orebody comprise Smith (1975) on the distribution of precious and volatile metals of the orebody; Gee (1970) on the geochemistry of the black slates overlying Rosebery; Eastoe (1973) who studied the Rosebery host rocks; Dixon (1980) worked on the carbonates; and Naschwitz (1985) studied the alteration pattern and metal zonation of the Rosebery orebody.

The first significant geological descriptions of prospects and regional geology of the area were those of Hills (1915). The stratigraphy and relationship of the Rosebery Group sediments and tuffs has been discussed by several authors including Finucane (1932), Campana et al. (1960), Campana and King (1963), Green (1983) and Corbett and Lees (in press).

Regional studies include isotope characteristics of the Rosebery, Farrell and Mt. Lyell ores, documented by Solomon et al. (1969). Eastoe (1980, 1981) attempted to define regional alteration characteristics and relate them to the stratigraphy, while Corbett (1979) related the volcanic sequences south of the Rosebery area to various stages in the evolution of a caldera complex, and later (Corbett, 1984, 1985) summarized stratigraphy and relationships of the Henty River- Williamsford area and compiled recent work in the Que River to Mt. Darwin area. Hall (1967) concentrated on the Hercules mine and surrounding area, while Fitzgerald's (1974) thesis on the White Spur area contains some geochemistry and petrology of the Hercules orebody.

Several E.Z. geologists have made significant, if little known contributions to the geology of various parts of the Rosebery-Hercules area. Throop (1974 a,b) reported on exploration at South Hercules, while Weeden (1981) documented drilling in the Black P.A. area. Reinhardt (1972), Williams (1974) and Mill et al. (1980) discuss aspects of exploration on the Mine Leases, and Mill (1983) documented the exploration history of the area. McDonald (1985) interpreted the Mt. Read Volcanics in terms of ancient arc sequences.

1.4 WORK COMPLETED

Mapping of the entire mine lease area, at 1:2500 scale, occupied the summers of 1982-84. These maps are stored in Rosebery (EZ plan Nos. 520-0018 to 520-0034 and 520-0139). This "fact mapping" was then reduced to 1:5000, and interpretive maps produced (Plans 1-4). A large scale interpretive map at 1:25000 has also been produced (Plan 5).

Logging of some 35,000 m. of drill core in detail, and plotting on numerous cross-sections (which are presented as Plans 6 and 7, a composite series of sections) has given much new information, and enabled the detailed stratigraphy and relationships described herein, to be established.

Approximately 380 thin sections, including 15 polished-thin sections provide the basis for petrological work, and are lodged with the EZ thin section collection. In the text, thin sections are referred to with a "TS" prefix, followed by either the appropriate rock sample number, or drillhole number and depth. Locations of thin sections referred to are given in Appendix 1.

1.5 ACKNOWLEDGEMENTS

The author gratefully acknowledges the assistance and guidance of Dr. Ross Large. Others at the University of Tasmania who contributed in various ways were Rick Varne, C. P. Rao, Max Banks, Peter Ruxton and Peter McGoldrick. Phil Robinson, Beth-Ann David and Sharon Adrichem performed the sulphur isotope analyses.

Keith Corbett and Geoff Green from the Tasmanian Dept. Mines were helpful both in field excursions and discussions, and Ralph Bottrill described the sulphides at South Hercules.

Geological staff at Rosebery were invaluable over a long period; in particular Geoff Iliff, John Howarth and Jim Farquhar, also John Mill, Ian McDonald and Ian Mathison. Bob Reid drafted many figures, and Anne Drake asisted in typing. Leigh Schmidt assisted in reviewing some sections of the thesis. The E. Z. Co. assisted financially and in other ways; their support enabled this thesis to be undertaken.

Finally, Jenny Lees helped with typing and provided moral support.

2 REGIONAL SETTING

The Mt. Read Volcanic Arc (Campana and King, 1963) is an arcuate belt of dominantly calc-alkaline volcanics in western and northwestern Tasmania. A compilation map of the Mt. Read Volcanics in western Tasmania is shown in Fig. 2, and the stratigraphic column for western Tasmania is shown in Fig. 3. Flanking the western margin of the volcanics is the Dundas Trough, a Cambrian depositional basin sequence of sediments with minor basic volcanics and felsic tuffs, which overlies sediments of the Precambrian Rocky Cape region. Basement rocks east of the volcanics are metasediments of the Precambrian region, lithologically similar but more metamorphosed than those of the Rocky Cape region (Williams, 1976). A schematic cross- section of the Mt. Read Volcanics and adjacent sequences is shown in Fig. 4.

At the base of the Dundas Trough sequence, the Success Creek Group of basal mixtite, and shallow water quartz-sandstone, mudstone, siltstone, dolomite, and minor conglomerates, rests unconformably on the poly-folded quartzwacke- slate sequence of the Oonah Formation (Brown, 1982). Conformably overlying is the Crimson Creek Formation, a thick sequence of mafic greywacke, mudstone, tholeiitic basalt and minor carbonates, (Brown, 1982), a feature being the presence of volcanics and mafic volcaniclastic sediments.

The Dundas Group consists of basal felsic epiclastic tuffs where it uncomformably overlies the Mt. Read Volcanics, and these pass upwards into flysch facies sediments with conglomerates. Within the Dundas Trough, sediments of the Dundas Group, containing a small proportion of felsic, volcanically- derived material, are considered to overlie the largely mafic-derived Crimson Creek Formation. Contacts between Crimson Creek Formation and Dundas Group are commonly faulted.

The Mt. Read Volcanics are now considered to consist of probably three separate arc sequences -

firstly the Darwin-Murchison sequence south and east of the Henty Fault Zone (HFZ), containing rhyolite-rhyodacite with minor andesite and granite, and a coeval flanking epiclastic sequence ("Western Sequence" of Corbett, 1979),

secondly the Rosebery sequence north and west of the Henty Fault of broadly dacitic character and lacking rhyolites and granites, and with no known flanking epiclastic or sediment sequence,

and finally the younger Tyndall Group of quartz-phyric arc volcanics deposited in rifts along the Mt Read - Tyennan boundary (Corbett and Lees, in press).

Between the north and south Henty Fault Zones (Fig. 2), an anomalous sequence of tholeiitic basalt, greywacke, shales and felsic epiclastic tuff, with gabbroic to ultramafic intrusives, is of completely different character to the arc volcanics on either side, and although

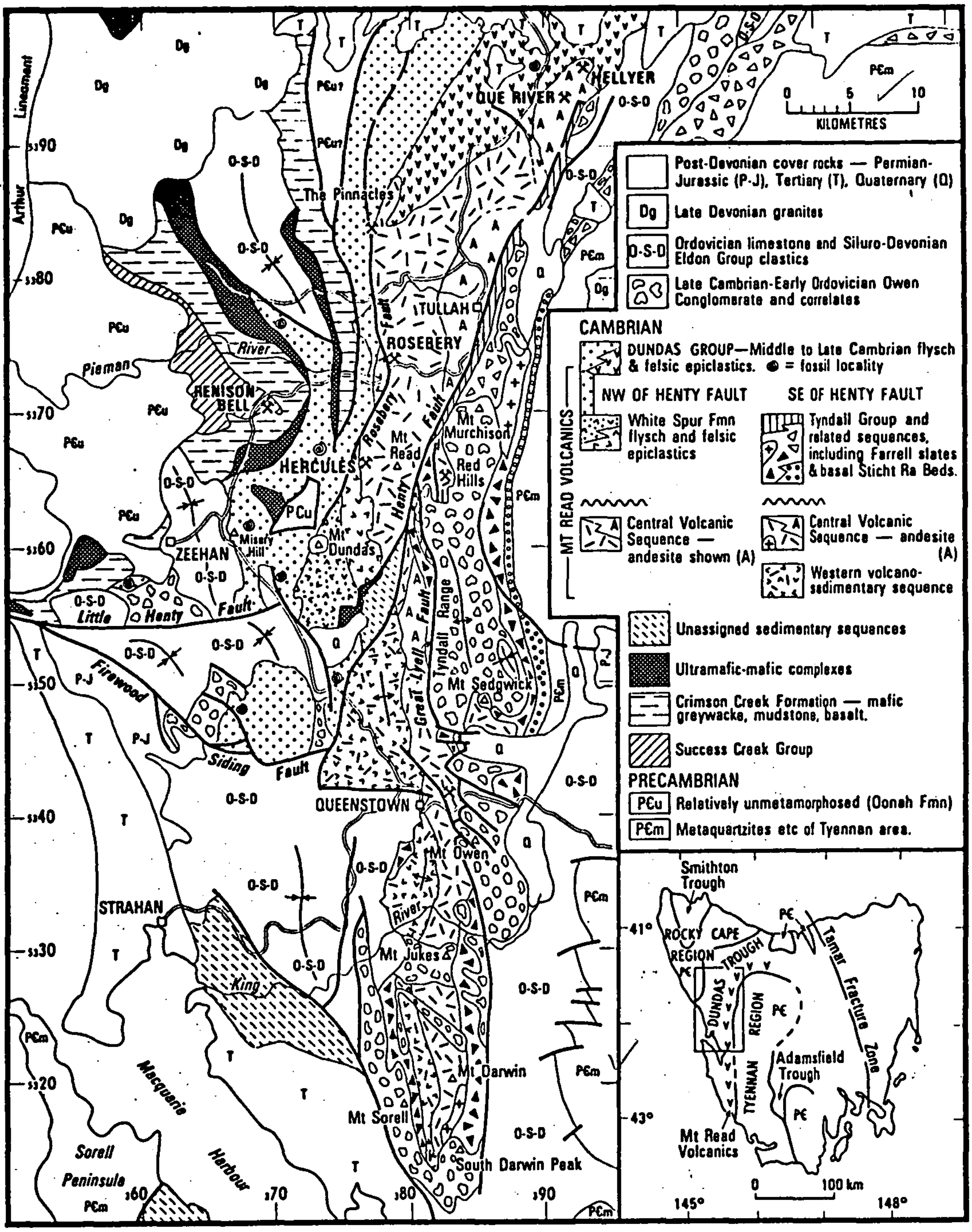


FIGURE 2 - Geological Map of central Western Tasmania

(From Corbett and Lees, in press)

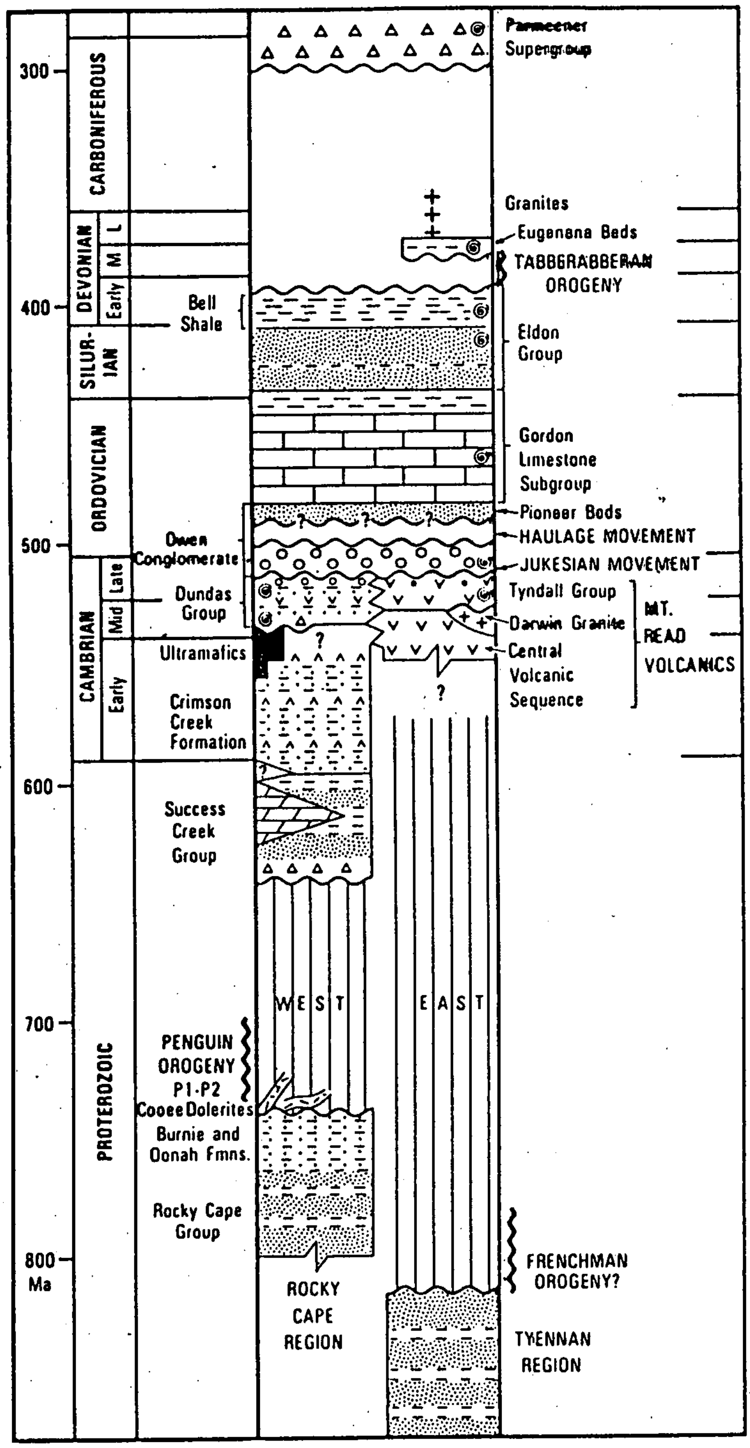


FIGURE 3 - Stratigraphic column for Western Tasmania (From Adams et al., 1985)

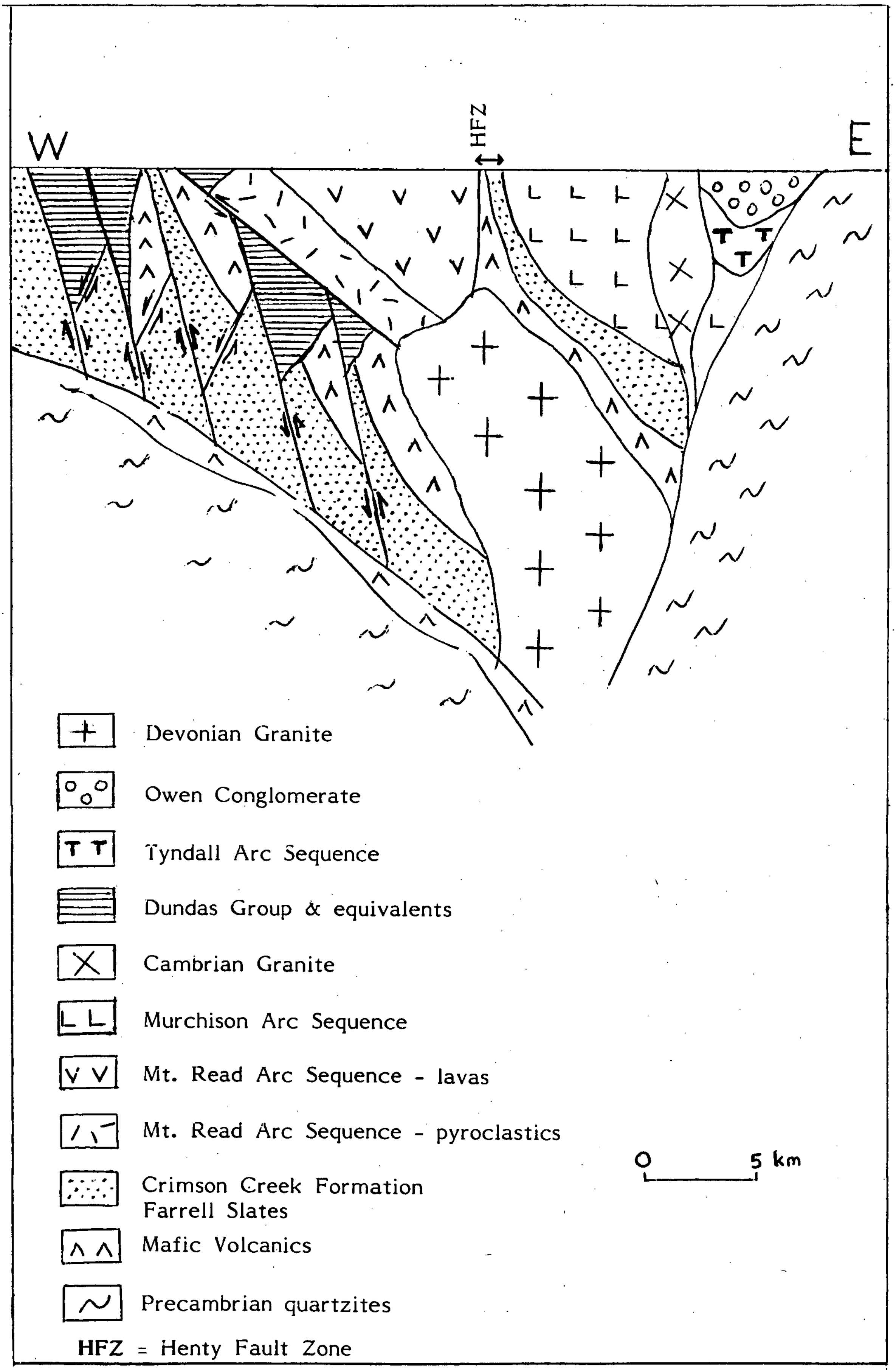


FIGURE 4 - Schematic cross section of Mt. Read Volcanics and associated sequences (after Crook, 1982)

superficially similar to the Crimson Creek Formation, contains arc-derived felsic epiclastics (K. Corbett, pers. comm.). It probably represents an oceanic basin sequence (Corbett and Lees, ibid., McDonald, 1985) that originally separated the Darwin - Murchison and Rosebery-Mt. Block arcs. It is suspected that closure of the basin, and compression during thrusting of the Dundas Group beneath the Mt. Read Volcanics, has juxtaposed the two arcs along the sutured HFZ.

The Darwin-Murchison sequence was divided by Corbett (1979) into a western volcano-sedimentary sequence of minor tholeiitic basalts (at the base), greywacke, shale, vitric tuff, quartz-phyric crystal tuff, and porphyritic intrusives; and a central sequence of feldspar-phyric agglomerate, tuff, lava and intrusives, with minor andesitic pyroclastics and intrusives. North of the HFZ in the Rosebery - Mt. Block sequence, no equivalents of the "western sequence" are known, as the Dundas Group is younger than the volcanics. The main volcanic belt here (also termed "central sequence") consists of feldspar - phyric ignimbritic tuffs and lavas (Corbett, 1984) but also minor quartz-phyric epiclastic tuffs, and massive dacitic to andesitic lavas.

The Mt. Read Volcanics have been metamorphosed to lower greenschist facies, producing in Rosebery a chlorite-sericite-silica assemblage, whilst at Que River prehnite-pumpellyite facies has been attained (Whitford, 1984). Cambrian hydrothermal activity associated with ore deposits has produced areas of intense silica-sericite alteration.

The recently re-defined Dundas Group is now known to overlie the Mt. Read Volcanics unconformably south of the Hercules Mine, and is at least in part equivalent to the Tyndall Group overlying the Darwin-Murchison arc sequence (Corbett and Lees, in press). The White Spur Formation at the base of the Dundas Group consists of epiclastic lithic tuffs, volcanogenic sandstones and shales, and is overlain by sandstones and shales of the Stitt Quartzite, dolomitic siltstones of the Westcott Dolomite, then fuchsitic Salisbury Conglomerate and felsic tuffs of the Natone Volcanics (previously members of the now defunct "Rosebery Group"). Faulting and disruption of the Dundas Group west of Rosebery is intense.

A thick sequence of silicic conglomerates to sandstones, the Owen Conglomerate, was deposited in fault-controlled basins developed on the Darwin-Murchison arc, in places onlapping the Tyennan region. The Jukes Breccia at the base of the Owen Conglomerate rests unconformably on Cambrian sequences (Campana and King, 1963), but the transition from Jukes Breccia to Owen Conglomerate may be locally conformable to unconformable (Corbett et al., 1973).

Thick, widespread fossiliferous Ordovician Gordon Limestone transgresses sediments of the Dundas Trough, or near Zeehan transgressively overlies Owen Conglomerate (Corbett, 1979). At the base of the Gordon Limestone, the Pioneer Beds rest on folded Owen Conglomerate (Corbett, 1979) which illustrates at least local deformation occurred at that time.

Recent work by geological staff at Mt. Lyell, however, indicates the folding of the Owen Conglomerate in this area may be due to differential movement during thrust faulting. Further clastic and minor carbonate sedimentation of the Eldon Group followed in the Silurian to Early Devonian.

A major period of folding with associated cleavage development, the Tabberabberan Orogeny, occurred during the Devonian, and is dated in Tasmania at 390-420 Ma (Adams et al. 1985). Granites intruded in the Late Devonian to Carboniferous, and lie at shallow depths in ENE trending belts (Solomon et al., in prep.). Metasomatic alteration, probably related to nearby granite, has affected the southern part of the Rosebery orebody. A deep drillhole at Colebrook Hill, some 3 km west of Rosebery, intersected granite at some 900 m depth (P. Collins, in prep.).

3 STRATIGRAPHY

3.1 TERMINOLOGY

The many and varied interpretations of the Cambrian sequences in the Rosebery area attest to the structural and stratigraphic complexity of the area.

Early interpretations by Hills (1915), Finucane (1932) and Hall et al. (1953), were largely over-simplifications, while those of later authors are represented in Fig. 5. The stratigraphic sequence described here is essentially the same as that of Corbett and Lees (in press), who recognised the unconformity at the base of the White Spur Formation (Dundas Group), and the significance of the Rosebery Fault. The stratigraphic chart is shown in Fig. 6.

The use of the terms 'Rosebery Series' or 'Rosebery Group' for the disrupted part of the Dundas Group west of Rosebery, is no longer warranted, nor is the term "Primrose Pyroclastics" (Campana and King, 1963) which was originally defined in an area on White Spur, now regarded as part of the White Spur Formation.

3.2. FOOTWALL PYROCLASTICS

3.2.1 Introduction

The "footwall pyroclastics" was the term used by Brathwaite (1969) to denote the part of the Primrose Pyroclastics occurring in the footwall of the Rosebery Mine. Brathwaite (1974) and Burton (1975A) followed this usage, but Green et al. (1981) and Green (1983) use the term to include rocks lying beneath the ore horizon in the Rosebery-Hercules area, also noting the feldspar-phyric mineralogy of these rocks. The latter loose definition seems appropriate here, as these rocks form a distinct mappable unit in a belt extending from the mine footwall north of Rosebery, to Hercules. As the pyroclastic nature of much of this sequence has been established (Green et al., 1981; this vol.), the term footwall pyroclastics can be retained.

The sequence underlying the "footwall pyroclastics" is not exposed. Green (1983) suggested dolomites equivalent to the Smithton and Jane Dolomites, are likely candidates for the preceding sequence. As thin sandstones containing material derived from Precambrian quartzite are present within the volcanics at Rosebery, Precambrian quartzites may have formed basement to the volcanics.

Subdivision and classification of the footwall pyroclastics into genetic types, comprising pyroclastic falls, pyroclastic flow, and surge deposits, as adopted in studies of recent volcanic

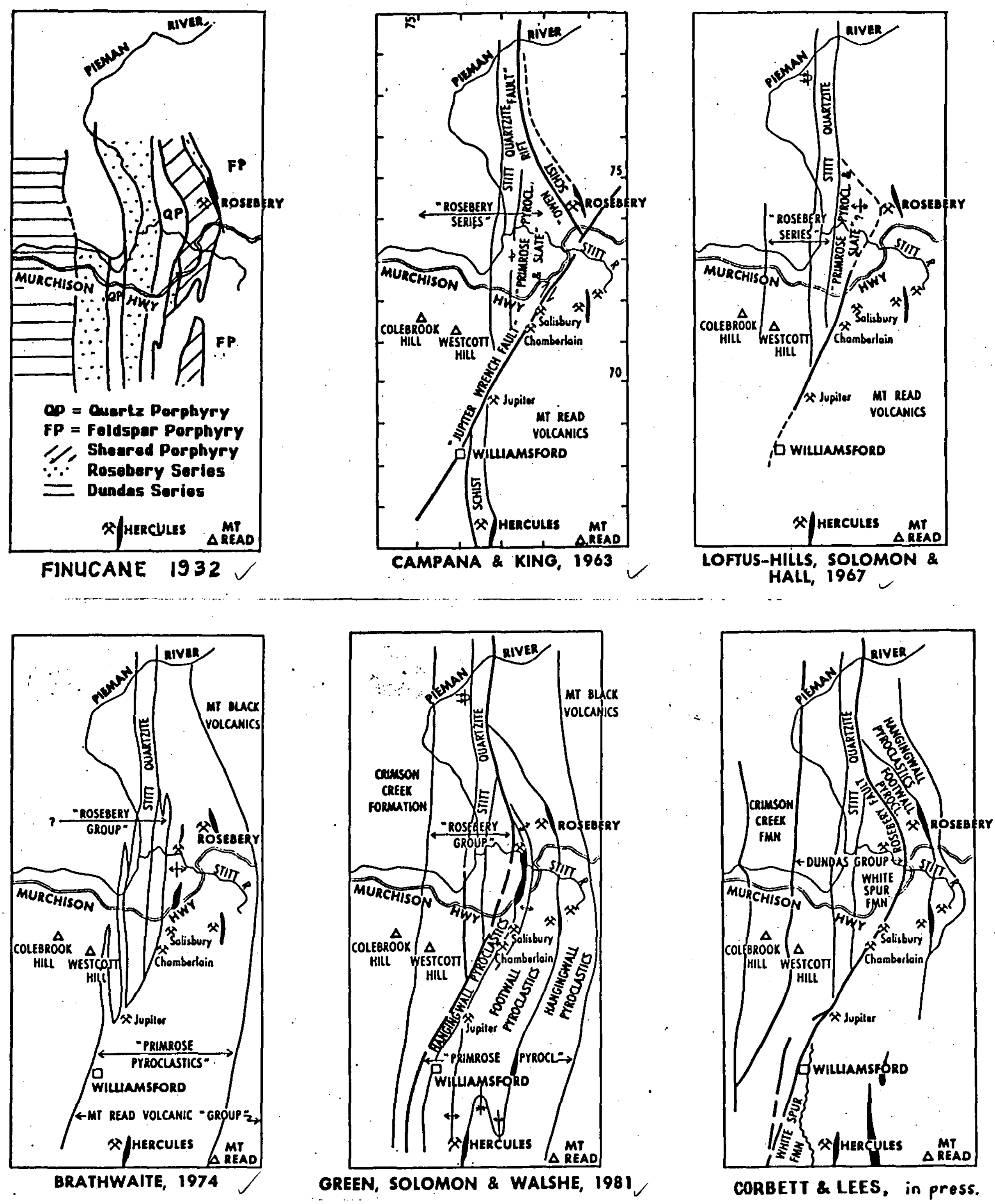


Fig. 5 Previous Geological interpretations of the Rosebery area (after Corbett and Lees, in press)

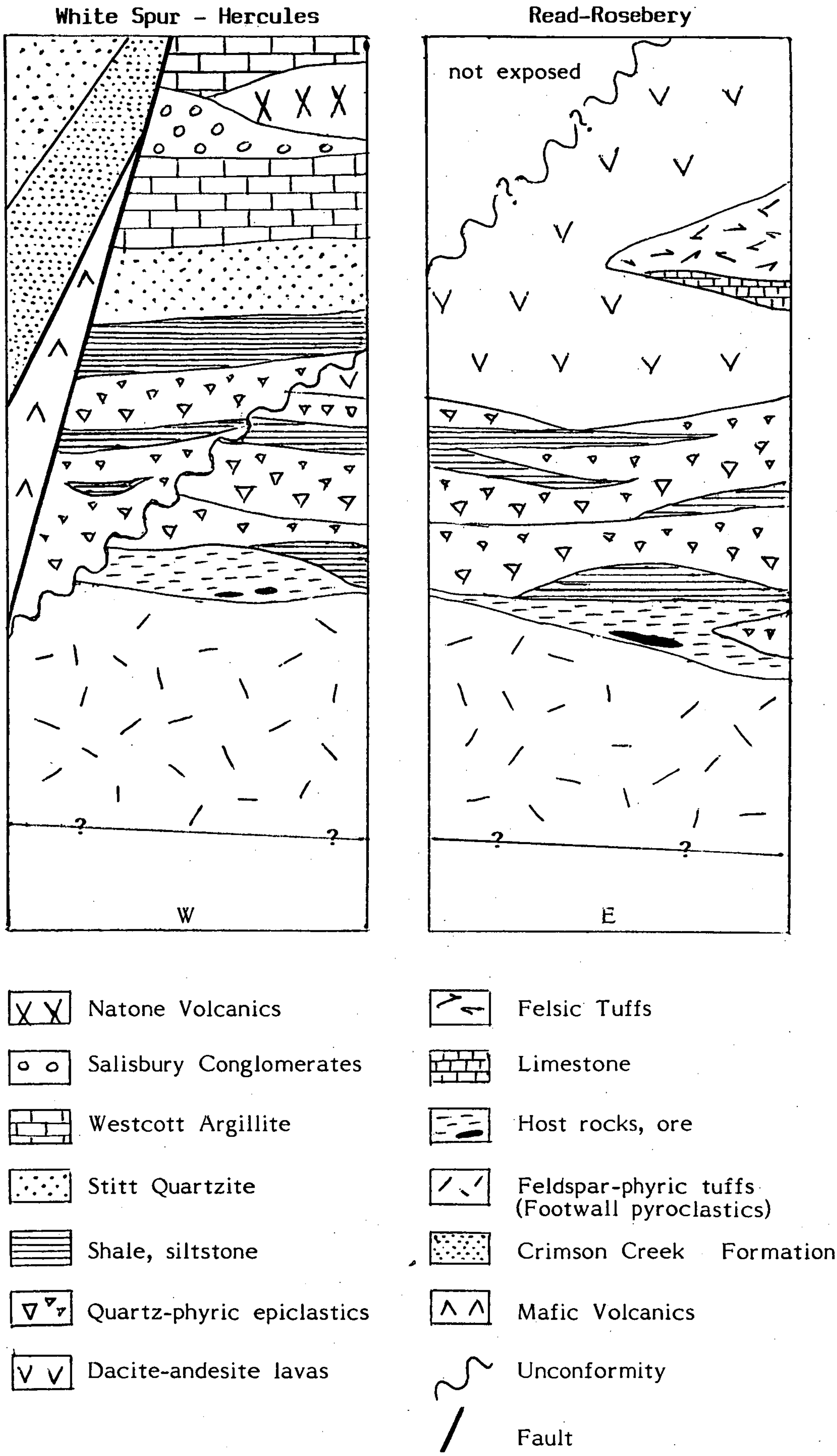


FIGURE 6 - Stratigraphic chart, Rosebery area, divided into western (White Spur-Hercules-Pieman River) and eastern (Mt. Read-Rosebery) segments

terranes (eg. Cas and Wright, 1983; Fisher and Schminke, (1984) is impractical in the Rosebery-Hercules area, for a number of reasons, given below:

- Individual units and contacts cannot be traced for more than a few metres.
- Differences between recent volcanics used in facies models, and lithified and altered original textures seen in the Mt. Read Volcanics.
- Difficulty in distinguishing welded from unwelded rocks, in both hand specimen and thin sections, as the only reliable criterion is the flattening of shards.

Interpretations of individual rocks, and of the footwall pyroclastic sequence as a whole, therefore, must be on a subjective basis.

3.2.2 Characteristics

The 'footwall pyroclastics' are felsic tuffs with variable proportions of vitric, crystal and lithic components. Crystal and clast types distinguish them from the overlying quartz-phyric epiclastics. Phenocrysts are commonly albite or albitised plagioclase, but K feldspar (sanidine) is locally present, and appears to be confined to lava-like units within the footwall pyroclastics. No quartz phenocrysts are known, although bodies with quartz and feldspar phenocrysts intrude the sequence.

Juvenile pumice clasts, often flattened "fiamme" are abundant, while accidental lithics of pelitic ash, felsic tuff, and possibly occasional felsic lava, are sparsely distributed and show variable rounding.

The lithological classification used during mapping is based on recognition of the various lithic, crystal and vitric components of a rock. These are prefixed in order of increasing abundance. Also recorded are the size of largest pumice clast observed; size and type of lithics; crystal type(s); matrix composition, and alteration.

Main variations noted in the footwall pyroclastics were in the proportions of components, and size and abundance of pumice. Others such as cognate lithics and accidentals such as ash tuff and felsic lava lithics, are relatively rare. Even in drill core, where a continuous section is available, lithological boundaries, and interpretation of the sequence in terms of modern ignimbrite facies, was only rarely possible. In attempting to interpret the sequence, a number of traverses were established to determine the variation within the section, and variation between sections.

3.2.3 Distribution

The "footwall pyroclastics" are present over a strike length of some 12km, from north of

Rosebery to Hercules (Plan 5).

North of Rosebery, the footwall pyroclastics wedge out against the Rosebery Fault, which also limits their thickness in the Rosebery Mine area to some 400m. Between the Jupiter Prospect and Williamsford, a greater thickness is exposed but this is still limited by the faulted western contact. The Copper Ridge Antiform (see Sect. 4.5.3) probably confines the thickness of footwall pyroclastics in the Williamsford-Bakers Creek area to approximately 500 metres; further south on White Spur the unconformity at the base of the Dundas Group progressively shields the underlying sequence.

3.2.4 Regional Relationships

As mentioned above, the western margin of footwall pyroclastics is bound by the Rosebery Fault from Rosebery to Williamsford. From Williamsford to White Spur the White Spur Formation unconformably overlies the "central sequence" (of Corbett, 1984) and progressively truncates the footwall pyroclastics, Hercules host rocks, and overlying tuffs.

From Rosebery to Koonya, the footwall pyroclastics are overlain with apparent conformity by sediments of the Rosebery host rocks. Where host rocks are absent, quartz- phyric tuffs may directly overlie footwall pyroclastics disconformably.

At the Dallwitz Prospect, tuffs and sediments of the Dallwitz-Jones Creek area (described in Sect. 3.5.5) are seen to overlie the footwall pyroclastics disconformably. The contact follows Talune Creek approximately NNE, but bedding in the pelitic ash of the overlying sequence is often at considerable variance to this, usually dipping steeply with a meridional strike, but in places striking nearly perpendicular to the contact. Additional indirect evidence for disconformity is that the thick sequence of feldspar-phyric tuffs in the hangingwall of Hercules is not present at Dallwitz and was probably removed by erosion prior to deposition of the Dallwitz-Jones Creek horizon.

In Hercules mine area, footwall pyroclastics are overlain by the Hercules host rocks, often with an unusual silicified volcanic breccia at the base.

3.2.5 Rosebery Footwall

Surface mapping shows that a number of units are recognizable, and in places contacts can be traced for several metres. Close to the Rosebery mine, alteration related to ore deposition has obliterated most primary features.

The majority of the section consists of an indeterminate number of pumiceous flows which may be distinguished on pumice size and abundance, alteration characteristics, or crystal type and content. Sharp contacts between flows were sometimes observed, and in one case a thin (1 to 10 cm.) ash tuff band separates flows (Fig. 7), while Fig. 8 shows several units with sharp contacts. The difference between the units is mainly the intensity of alteration, which probably reflects a primary lithological difference, perhaps in porosity. Sericitized feldspar is still present, but no shard textures (TS 54003).

Two drillholes, R1121 from 8 level, and 85R from surface, traverse the entire footwall sequence through to the Rosebery Fault, a stratigraphic distance of 350-400 metres (Plan 6). Although several distinct broad units can be recognised, much detail and obviously many contacts are masked by the alteration. Euhedral, glomeroporphyritic feldspar was noted in one section (TS R1121 550ft.), a feature also noted in welded footwall pyroclastics south of Rosebery (TS LB270 194.9m, LB271 130.5m).

3.2.6 Rosebery Lodes - Bald Hill

Altered tuffs are exposed in the footwall of Rosebery Lodes, and pass into unaltered tuffs further into the footwall on Bald Hill and across to the Rosebery Fault some 750 m. west of Rosebery Lodes (Plan 2).

A number of course pumiceous lithic tuffs are present on Bald Hill, well exposed on the Mt. Read road at 5371600N, 378400E. Flattened pumice to greater than 50 cm. length, and felsic lithics are present in several units separated by medium grained ash - rich and crystal (feldspar)-rich tuffs (TS 54350). Further west, a number of intrusives disrupt a mixed pumiceous crystal-lithic tuff and fine grained ash sequence which shows well - preserved shards in an unwelded crystal- vitric tuff (TS 54866). Alteration increases towards a large quartz-amygdaloidal lava/ intrusive exposed near the Mt. Read gate (5371360N, 377650E) adjacent to the Rosebery Fault and intersected in drillhole CP 281.

At one point (5372290N, 378700E) within the sequence several thin (1- 2 cm.) sandstone beds, reported (K. Corbett, pers. comm.) to be largely composed of grains of Precambrian quartzite, are transgressive to local strike.

3.2.7 Koonya- BH 285

A nearly continuous section, based on Koonya drill - holes and recently drilled BH 285, covers the sequence from the Rosebery- Rosebery Lodes sediment horizon to quartz-phyric lava/ intrusive adjacent to the Rosebery Fault.

Quartz-sericite and chlorite alteration overprints have oblitered most primary features in the Koonya area, but there is a very localized occurrence of siltstone and epiclastic tuff with siltstone clasts at 5370 990N, 378300E on the Mt. Read road.

Fig. 7 Thin ash tuff bed within pumiceous tuffs, Rosebery Footwall (5373940N, 378580E)

Fig. 8 Ash flow tuffs in footwall pyroclastics (5,374,100N, 378,440E)

Numerous drillholes in the Koonya area are unfortunately of little use in interpretation of the volcanics as most rocks are considerably altered. Numerous thin sections, however, give an indication of the original lithologies. Pumiceous lithic tuffs (eg TS KP 198 34ft., 83ft.) and vitric tuffs (eg TS KP 197 95ft.) rarely with preserved shard textures (TS KP 201 35ft.) are most common. Accidental lithics of strongly welded tuff in an unwelded shard-rich matrix (TS KP 196 519ft), show that strong welding has taken place within the pyroclastic sequence.

A common feature of the Koonya rocks are the quartz-replaced feldspar phenocrysts (TS KP 197 191ft.) which surround a quartz - amygdaloidal lava or intrusive (TS KP 198 193 ft.). The lithic and vitric tuffs encountered in the Koonya drilling outcrop poorly, but along the Mt. Read road they contain flattened pumice to 100 cm length.

In BH 285, numerous thin (1 to 10 cm) bedded sandy and ashy tuff bands separate pumiceous flows having subtle variations in pumice size and abundance, type and abundance of accidental lithics, crystal content and degree of alteration. Strong silicification in tuffs adjacent to the quartz - amygdaloidal lava/intrusive intersected in BH 285 is comparable to that in CP 281 further north, and mapping suggests that the lava/intrusive is a continuous body with a strike length of some 1.5 km.

3.2.8 North Hercules- Jupiter

A rough track joining the Mt. Read road to the Williamsford Road, provides a section from the Dallwitz epiclastics to Rosebery Fault, a distance of some 1,450 metres. Drill hole H 955 intersects the western part of this sequence at depth.

Two parts to the sequence can be subdivided by a lithological change at 377100E. To the east, coarse lithic tuffs commonly contain flattened pumice 30-50 cm length, while to the west many 5 to 10 metres thick units, usually contain pumice to 5 cm in length, also numerous felsic lithics, and are separated by thin ash tuff bands or sharp contacts. A basal lithic - rich zone, and several pumice-rich tops to units (assuming an E facing sequence) have been mapped.

The Pb-Zn-barite horizon at the Ring P. A. prospect is contained within vitric tuffs, toward the base of the exposed sequence (see Sect. 3.3.6), and is underlain by pumiceous tuffs containing both flattened and spheroidal pumice often 50 to 100 cm length. The Rosebery Fault, exposed on the Williamsford Road, defines the western limit of footwall pyroclastics.

H 955 shows a monotonous series of pumiceous vitric - crystal - lithic tuffs (TS H 955 350ft., 530ft.) containing ashy lithics (TS H 955 1016ft., 1302ft.). Rare thin ash beds define contacts between units.

At the Jupiter prospect strong alteration has obliterated most primary textures, but a vitric tuff just east of the alteration zone shows well - preserved shard textures (TS 47166, Fig. 9).

3.2.9 Hercules

Tuffs in the footwall of Hercules are well exposed along Bakers Ck. in the mine footwall, and along the haulage road to Williamsford. A thickness of some 700 m of footwall pyroclastics is exposed, about one half of which have undergone significant alteration. The stratigraphic thickness represented is probably considerably less because of flat dips and the presenceofthe Copper Ridge Anticline.

The altered tuffs in the Hercules footwall consist of deformed pumice, usually 10 to 20 cm. but up to 100cm. length, in a silicified matrix (Figs 10,11). These rocks appear to be quite uniform, containing coarse pumice in a silicified matrix, which, although deformed by the cleavage, show consistent shallow east dips. Variation in pumice size and concentration may be a reflection of internal differences within flows, and it is likely that the sequence comprises a number of flows, but contacts are not distinguishable. Feldspar is smeared and sericitized, or destroyed, as are most primary textures.

Just north of Hercules, a wedge of unaltered footwall shows good evidence for welding in both outcrop (Fig. 12) and in thin section (TS 55280). The unaltered rocks in Bakers Creek are coarsely pumiceous, with felsic lithics and feldspar crystals. No contacts or ash beds have been observed.

The White Spur Formation overlies the "footwall pyroclastics" unconformably at 5367070N, 375905E.

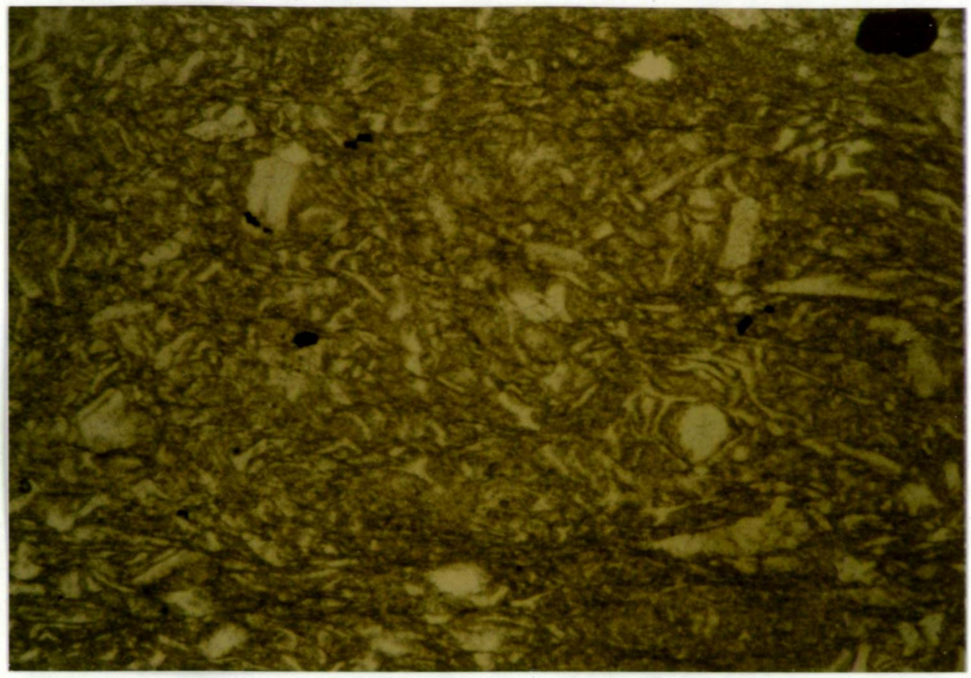
3.2.10 Other Lithologies within Footwall Pyroclastics

Quartz-phyric Intrusives

A number of thin, discontinuous intrusives of limited extent are known within the footwall pyroclastics. Outcrops are on Karlson's Knob (TS 54636), in the Rosebery town, on Bald Hill, and on the Mt. Read road. They consist of embayed quartz and completely sericitized feldspar, in a fine sericitized quartzo - feldspathic groundmass.

Quartz- amygdaloidal Lava/ Intrusive Bodies

At Koonya, a small lava or intrusive occurs close to stringer-style mineralization. Quartz grains (sheared phenocrysts?) occur in a sericitized groundmass (TS 54911), but other thin sections show the rock to be composed of abundant quartz spherulites with fluid inclusions (TS KP 197 177ft., KP 197 412ft.), or quartz-chlorite amygdales, again with fluid inclusions, and chlorite flecks possibly after mafic phenocrysts, in a sericitized matrix (TS KP 198 283').



1mm

Fig. 9 Unwelded shard-bearing vitric tuff, Rosebery footwall
TS 47166 pp light

Fig. 10 Deformed pumice, Hercules footwall (5367555N, 376500E)
(Note: lens cap top of frame)

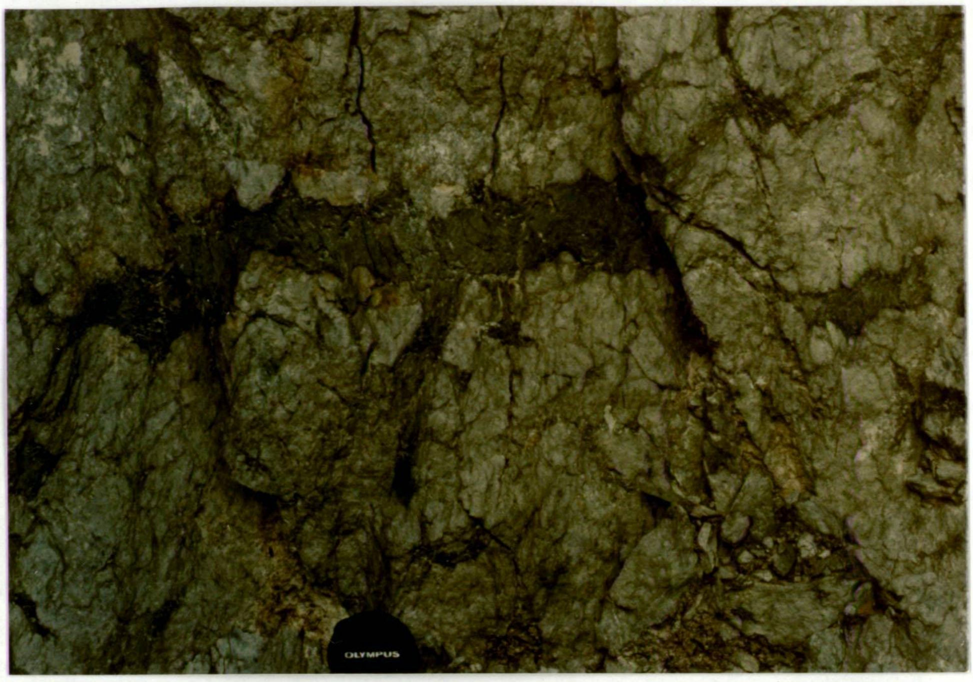


Fig. 11 Deformed pumice, Hercules Footwall (5,367,555N, 376,500E)

Fig. 12 Welded pumice, 4 Level Hercules (5,367,070N, 376,700E)

A large body of strongly altered, usually quartz - amygdaloidal lava or intrusive, extends from north of the Jupiter prospect to the Chamberlain mine. The Rosebery Fault limits its western contact along most of its 1.5 km strike length. It consists of quartz amygdales (sometimes flattened and stretched), and sericitized and/or silicified feldsper phenocrysts, in a spherulitic matrix (TS 55743, 55744, CP 281 60.2m, 108.2m). The presence of amygdales would tend to indicate these are extrusive rather then intrusive bodies.

Mineralized horizons, Ring P.A. and Jupiter

A thin, discontinuous mineralized horizon at Ring P.A. and Jupiter (see Sections 6.8, 6.9), is hosted within shard - bearing vitric tuff (TS 55749) which is often cleaved, sericitized and silicified (TS 55748). Between Jupiter and Ring P. A., a 10cm. band of barite probably marks the trace of the mineralized horizon, among uniform, ash- rich feldspar - phyric tuffs.

Quartz-Sandstones

A number of occurrences of quartz-sandstone bands are known between South Rosebery and Koonya. At South Rosebery, (5373245N, 379035E) and in the Stitt River (5373075N, 378930E) a one-metre thick quartz sandstone (TS 54490) consists largely of Precambrian quartzite grains (showing folded pelitic laminae) in a quartz- chlorite matrix with minor tourmaline needles. On Bald Hill (537280N, 378705E) several 1- 2cm sandstone bands occur. A similar band occurs in drill hole BH 285, a few hundred metres further south. All the above occurences are within 10- 15m. of a quartz-tourmaline vein-breccia, which outcrops sporadically in a linear trend from South Rosebery to Bald Hill and was intersected in BH 285.

If these Precambrian-derived sandstones are of sedimentary origin, their presence has a number of implications. Firstly the source of Precambrian detritus must be quite close, and secondly it indicates a negative relief of the volcanic terrain to allow even a small sediment supply to enter.

Sandstone dykes, a few centimetres thick and transgressing the host volcanics, are known to occur adjacent to the Great Lyell Fault near Queenstown (K.Corbett, pers. comm.). The sandstone bands described above may have a similar origin. Their cross-cutting nature means that a purely sedimentary origin for the sandstone is unlikely, and that a possible alternative explanation is that quartzite, underlying the volcanics, has been forced into a fracture by lithostatic pressure, the fracture subsequently being filled by a quartz-tourmaline vein.

3.2.11 Synopsis

As seen in the above descriptions, a complex stratigraphy exists within the "footwall pyroclastics". Green (1983) considered the footwall pyroclastics to consist of a number of pyroclastic flows, including both welded and unwelded homogeneous units. Detailed correlations have not been attempted, but a number of generalizations can be made. Firstly there is a consistent and widespread lithological association of pumiceous, sometimes welded, feldspar - phyric vitric - crystal - lithic tuffs, and only rare instances of other lithologies. These tuffs have a number of features, such as lithic-rich basal zonesand pumice - rich tops, that indicate emplacement as flows, and other features such as ash tuff layers, and welding, that indicate that the sequence is composed of a number of ignimbritic ash flow tuffs.

Sediments within this sequence are rare, and those present contain grains of Precambrian quartzite. Their presence indicates a nearby source of Precambrian quartzite, also that the volcanic belt at the time had a negative relief, which is quite normal for ash-flow producing rhyolitic volcanoes such as Lake Taupo, NZ.

Eutaxitic textures are preserved sporadically in footwall pyroclastics. The significance of welding is in the interpretation of depositional environment, thus it is relevent whether welding can take place under water, and to what, if any, confining depth.

Theoretical considerations of pyroclastic flows entering water indicate that welding is likely if the flow can maintain its identity and it has a density greater than water (Sparks et.al., 1980). Although numerous examples of welded ignimbrites emplaced in shallow water are found in the literature, in many cases subsequent studies have shown water depths to be extremely shallow. Welded ignimbrites of the Capel Curig Formation of Ordovician age in North Wales, overlie fossiliferous marine sediments (Francis and Howells, 1973) however sedimentological work on the cross- bedded marine sands indicate a water depth of less than 5 metres (Cas and Wright, 1983), which is probably not enough to prevent welding of a large pyroclastic flow. The Dali ash flow deposit on the island of Rhodes, Greece, described as welded tuff within deep marine sediments by Mutti (1965), was subsequently shown not to be welded (Wright and Mutti, 1981). In South Wales, Lowman and Bloxman (1981) describe welded ignimbrites associated with graptolite - bearing shales and basaltic pillow lavas from the Fishguard Volcanic Group. Carey and Sigurdsson (1980) have traced the Roseau welded ignimbrite of Dominica into an unwelded submarine equivalent, and, as Cas and Wright (1983) point out, there are no known Recent subaerial welded ignimbrites that can be traced into a welded submarine equivalent.

The "footwall pyroclastics" are interpreted as an ash - flow sheet, composed of compound ignimbritic flows presumeably with associated air - fall tuffs. Green (1983) argued for a largely subaerial environment for deposition of the welded footwall pyroclastics, but a significant part of the sequence is not welded and some sections were deposited subaqueously.

3.3 ROSEBERY HOST ROCKS AND EQUIVALENTS

3.3.1 Introduction

Directly overlying the feldspar-phyric footwall pyroclastics in many areas are tuffaceous sediments which host mineralization at Rosebery. The Rosebery host rock horizon can be traced intermittently from north of Rosebery to the southern end of Rosebery Lodes. Where the host rocks or equivalents are absent, quartz-phyric tuffs directly overlie footwall pyroclastics.

The Hercules host rock sequence has many similarities with Rosebery and may be at the same stratigraphic postion, but as the two cannot be correlated with certainty, they are discussed separately.

3.3.2 Rosebery Host Rocks

The Rosebery host rocks have been described by Brathwaite (1969, 1974), Eastoe (1973), Green et al. (1981) and Green (1983). General features are shown in Fig. 13.

In the mine area, host rocks consist of tuffaceous, sericitic siltstones, with minor crystal tuffs, sandstones, and the sulphide lenses. The base of the host rocks is often difficult to distinguish because of overprinting chlorite- silica- sericite alteration, but some pumiceous, epiclastic tuffaceous units probably derived from the footwall pyroclastics occur towards the basal contact. The siltstones comprise varying proportions of quartz, sericite and chlorite, often with disseminated to bedded fine pyrite, and form the bulk of the host rocks. Near the top of the host rocks, and above the baritic H lens position, are an increasing proportion of graded greywacke and sandstone beds, often fining upward into siltstone

At the north end of the orebody, a distinctive unit of crystal tuff is present within the host rocks, above the lower ore position and below the upper barite ore position. Thin sections (TS 47152, 47153) show the unit to consist of abundant euhedral albitic plagioclase, embayed quartz and various rounded lithics in the sericitic matrix. These features suggest some reworking has occurred. Structure contours of the unit show it to thicken northwards and with depth. Of significance is the first appearance of quartz phenocrysts immediately above the ore position and mineralized massive carbonate at the north end.

North of Rosebery on the Bobadil track (5375540N, 378085E) 10 cm of bedded tuffaceous sandstone marks the base of the host rocks, and is overlain by quartz - phyric reworked tuffs. Strike of the host rocks here, and exposures of hangingwall quartz-phyric tuffs further north on the track, mean that the base of host rocks must intersect the Rosebery Fault. Drill hole 71R, about 1 km. north of the mine, intersects a host rock sequence containing a thin mineralized zone at the base, then thick reworked quartz - phyric tuffs and

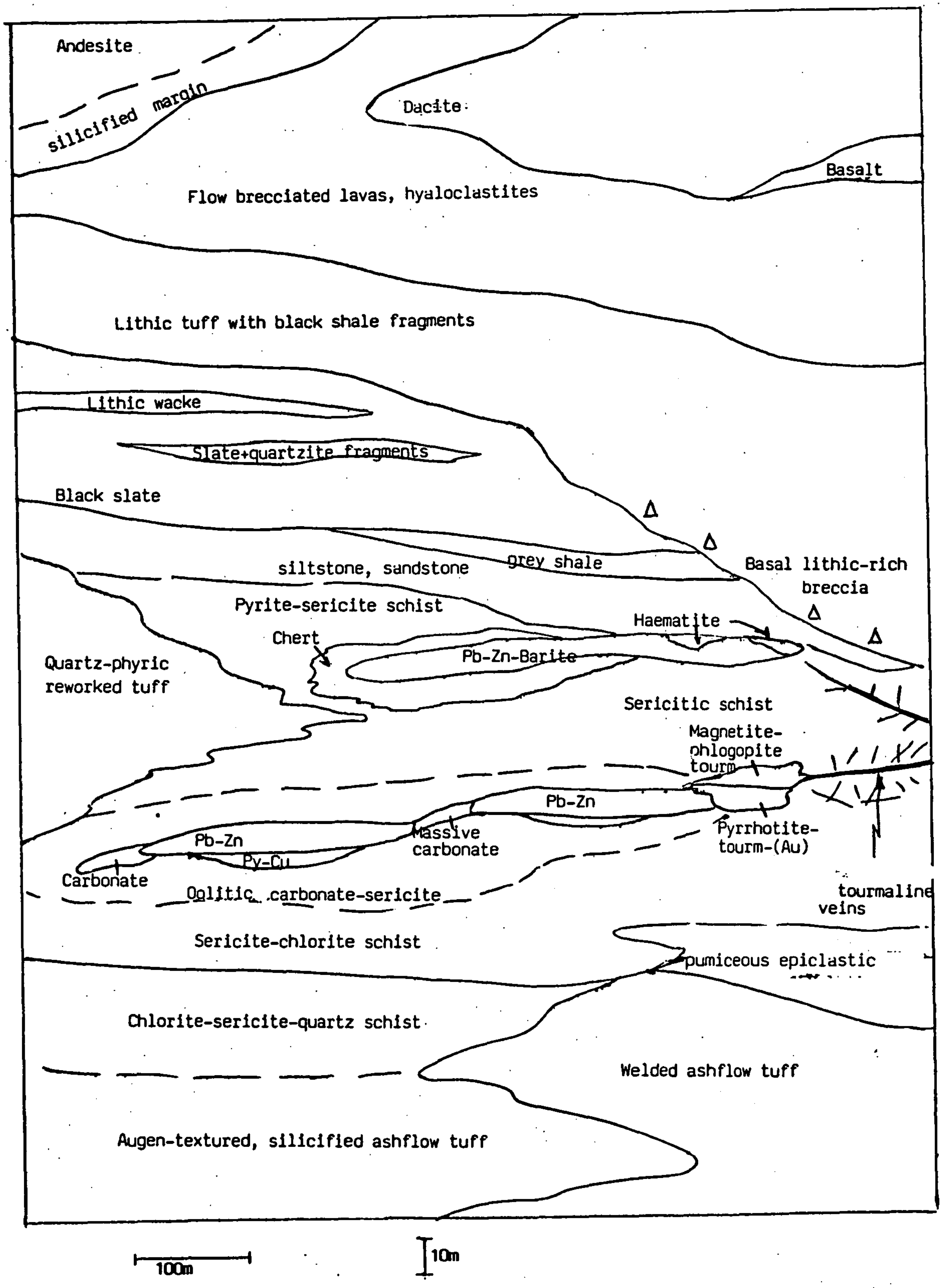


FIGURE 13 - Diagrammatic Rosebery Host Rock Sequence

(Not to scale.)

black slates (Plan 8). The flat dip of the sequence is due to the westerly swing of the base of the host rocks on the surface, combined with the thickening of the "host rock", now largely quartz- phyric tuffs and epiclastics, between footwall pyroclastics and black slate.

Surface mapping shows the host rocks to thin and disappear at the south end of Rosebery, leaving quartz - phyric tuffs directly overlying footwall pyroclastics. Between Rosebery and Rosebery Lodes, drillholes LB 270, LB 271 and LB 287 provide the only sections. Poorly bedded reworked tuffs and volcanogenic sandstone are present in the host rock position.

A deep drillhole at the southern end of Rosebery, 73R, intersected a different sequence some 500m. below the surface. A chilled, perlitic lava (TS 73R 457.5m, 470.3m, 517.7m, 554.6m, 583.3m) overlies footwall pyroclastics, which are composed of plagioclase crystals in a shard- bearing matrix (TS 73 R 640.2m), and is draped by possible host rock equivalents in poorly bedded psammitic to pelitic ash with quartz phenocrysts (TS 73 R 441.3m).

The black slates at Rosebery often overlie the host rocks and are described by Gee (1970). They consist of finely laminated grey to black shales, now composed of quartz, sericite and chlorite with a minor organic component (Gee, 1970). Although originally extensive over the Rosebery orebody, the black slates have in many places been removed, and incorporated as accidental lithics in the quartz- phyric tuffs, leaving relics of slate in several areas, particularly over the northern A and B lenses. Pyrite laminae, and occasional pyrite nodules, are now partly transposed into the cleavage. Thin quartz - carbonate veinlets are abundant in places, subparallel to cleavage.

Within the black slate, several sandstone or lithic wacke beds, from 10 cm to 100 cm thick, are composed of rounded to subrounded quartz crystals, shale and slate clasts, and small clasts of quartzite, siltstone and sericite schist, some clasts exhibiting folding (TS 55040). Green (1983) also noted folded Precambrian quartzite grains, interpreting the origin of the beds as turbidites with their provenance in the Tyennan region to the east. It is also conceivable that quartzite was derived from a Precambrian inlier closer to Rosebery, such as the Oonah Quartzite near Mt. Dundas (Fig. 2) which is also on the north - west side of the Henty Fault Zone.

3.3.3 Rosebery Lodes

The sequence at Rosebery Lodes is analogous to that at Rosebery, but there are a number of differences. Tuffaceous sandstones to reworked tuffs, with minor pelitic ash (TS 47164) is up to 60 metres thick, and are in general thicker and coarser grained than the host rocks at Rosebery. Pyrite is commonly present, but with only minor base metal mineralization in a poorly defined horizon containing barite, base metals and minor Au and Ag (see Sect. 6.5).

Overlying the host rocks are black slate similar to those of Rosebery and contain one or more lithic wacke/sandstone beds. These were originally more extensive sheets, and are now preserved as relict lenses, having been eroded prior to deposition of the quartz - phyric tuffs. A fine-grained, black rock from south Rosebery Lodes, previously mapped as black slate, is in fact a quartz- tourmaline rock (TS 55051). Both fine bedding and cleavage are retained, but the origin of tourmaline is not clear in this case.

Several recent drillholes south of Rosebery Lodes (RLP 274, RLP 275, RLP 287) have enabled the geology of this area to be interpreted. Quartz-phyric tuffs thin and pinch out in this area, to be replaced in part by a fine - grained, altered and weakly mineralized perlitic lava or devitrified obsidian. At the southern end of the concentrated drilling at Rosebery Lodes, in drillhole RLP 287, a thin, poorly bedded ashy tuff overlying feldspar - phyric tuffs of the footwall pyroclastics is followed by altered lavas (TS RLP 287 274.4m, 300.5m), which are then overlain by relatively unaltered dacite lava (TS RLP 287 113.5m).

In the southern - most drillhole, RLP 275, a chlorite - pyrite - chalcopyrite stringer zone lies at the top of weakly silicified footwall pyroclastics, and is succeeded by approximately 10m of vitric tuff representing the host rocks, then a sequence of strongly altered tuff or, more probably, chilled lava.

The host rock position can be traced further south into Talune Creek, but then lack of outcrop in thick forest inhibits interpretation between this area and Dallwitz, where the Dallwitz-Jones Creek sedimentary/ epiclastic horizon lies directly on footwall pyroclastics.

3.3.4 Hercules Host Rocks

Detailed stratigraphy of the Hercules host rocks in the vicinity of the mine is presented in Section 6.3.2.

The Hercules host rocks extend from their faulted northern contact on 4 level at 5366910N, 376700E to the White Spur track at approximately 5365150N, 376350E, where they are truncated by the unconformity at the base of the White Spur Formation. Their western contact especially is difficult to define due to a combination of shallow, open folding, and topography. In the Hercules mine area, a number of large, open folds, with an axial plane cleavage averaging 160°/70°E, are present but the host rocks have an overall east dip of 20-30° at 170° strike. At West Hercules, dips are variable on folds showing vergence close to that of an anticlinal closure.

The host rocks terminate against a zone of siliceous schist exposed on the 4 level road, the Mt. Hamilton Fault. The presence of footwall pyroclastics on the north side of the fault opposite host rock and shale, indicates at least a right-lateral movement for the fault; the vertical component is unknown. An intrusive rhyolite "appears" from the fault and persists to East Hercules. Host rocks are absent north of the fault, but their trace, marked by the contact of quartz-phyric tuffs overlying feldspar-phyric footwall pyroclastics, strikes northeast around Mt. Hamilton. A thin pelitic ash or siltstone (TS 55481) and associated quartz-wacke in the Ring River, which occur on this horizon, are probable equivalents of the host rocks.

At the base of the Hercules host rocks, a distinctive altered volcanic breccia 0-30 metres thick, is often present. It consists of strongly silicified lithics and sericitic pumice (both to 10cm. length), in a siliceous matrix (Fig. 14). This is overlain by up to 100m. of variable, poorly bedded, usually ashy tuffs that contain fine bands of variously sized and textured carbonate spheroids (TS 55277). Pelitic to psammitic ash tuffs consist of finely crystalline quartz in a fine, partly sericitized matrix (TS 55360, 55504) sometimes with shards (TS 55449). A distinctive, cherty pelitic ash to 2m. thick occurs at the top of the host rocks near M lode, and is overlain by thinly interbedded shale and lithic-wacke, of grey to black often pyritic shale, and packed siliceous and shaley pelite fragments, also quartz and feldspar crystals in a sericitic matrix. This unit varies from 5 to 30 m. thick, and can be considered a correlate of the black slates at Rosebery, as it is in the same relative position.

3.4 QUARTZ-PHYRIC EPICLASTICS

3.4.1 Introduction

Brathwaite (1969) divided the Primrose Pyroclastics of Campana and King (1963) in the mine area into footwall pyroclastics, host rocks and black slate, and massive pyroclastics. He noted that the massive pyroclastics contain albite and quartz crystals, but states the footwall pyroclastics are "mineralogically similar to the massive pyroclastics".

Green et al. (1981) and Green (1983) noted the difference in mineralogy between the feldspar-phyric footwall pyroclastics and quartz-feldspar-phyric massive pyroclastics, and the different clast assemblage and sediment lenses in the latter. The term massive pyroclastics was retained even though the authors recognised that the bulk of the unit was probably emplaced as submarine density flows or slides.

Here, the non-generic term quartz-phyric tuff is used to denote these rocks individually or on outcrop scale, as probably both epiclastic and minor pyroclastic flows are present within them, but the name "quartz-phyric epiclastics" can be used in a regional context.

Quartz-phyric epiclastics within the central sequence overlie the footwall pyroclastics and/or host rocks, and vary in thickness from approximately 1000m. at Bastyan Dam to some 200m. at Rosebery, and about 400m. at Rosebery Lodes - Dalmeny, then thin and disappear near Koonya. At Hercules, feldspar-phyric tuffs similar to the footwall pyroclastics occur extensively within a suite containing several quartz-phyric tuff and sediment units.

Fig. 14 Silicified lithic breccia, base of Hercules Host Rocks, A Lode.

Characteristics which distinguish the quartz-phyric epiclastics from feldspar-phyric footwall pyroclastics, apart from the definitive quartz+feldspar phenocryst assemblage, are the diverse clast types and their frequency, distribution and rounding. Basal lithic-rich breccias often mark the base of recognisable flows, while the tops are marked by poorly bedded reworked tuffs, volcanogenic sandstones and shales.

3.4.2 Bobadil - Pieman River Section

The Rosebery Fault defines the western limit of quartz-phyric epiclastics, while to the east it is overlain by a thick andesite-basalt sequence. Between these limits, approximately 1,200 m. of poorly exposed (except for man-made outcrop at Bastyan Dam) quartz-phyric tuffs with minor sedimentary horizons, and a quartz-feldspar porphyry, are present. Several drillholes in the area have enabled some stratigraphic interpretations to be made.

The dominant lithology is made up of a number of repetetive units (or flows), with a number of features in common. Basal lithic breccia of abundant coarse angular to rounded matrix-supported clasts, including some identical to the underlying sediment horizon, is commonly present. Clast types are commonly sedimentary (TS BD 269 268.4m.) but include pelitic ash and spherulitic rhyolite lava (TS BD 269 188.8m.). Green (1983) describes rafts of shale to ten metres length within the quartz-phyric lithic tuff. The basal contact of lithic-rich breccia is in places demonstrably erosional upon shale/siltstone, but sediments are often not present whereby the lithic-rich breccia overlies "normal" quartz-phyric tuff.

Lithics gradually decrease in size and abundance away from the lithic-rich base, becoming lithic-crystal tuff of occasional rounded lithics, abundant feldspar and round quartz crystals (shown in Fig. 15), in a shard-bearing matrix (TS 55572, 55573). Reworking, evidenced by poor bedding and depletion of matrix, may occur toward the top of the unit, which then grades into, or is sharply overlain by, volcanogenic sandstones, siltstones and shale (TS BD 269 227.3m.) and pelitic ash (TS BD 269 44.3m.).

Within shale dominated parts of the sequence at Bobadil (5376750N, 377150E) and near Bastyan Dam (3377910N, 378190E) shale - hosted "breccia" of chaotic disrupted felsic tuff lithics in chaotic, swirled siltstone, form an integral part of the sequence. Their origin is discussed later (Sect. 5).

Of particular note in the quartz - phyric tuffs at Bastyan Dam (now submerged) is a five metre wide zone with sulphide lithics to boulder size, which comprise some 10% of the rock. These include massive sphalerite, massive pyrite, and siliceous schist with disseminated sphalerite. The lithics are obviously derived from a massive sulphide deposit.

A quartz-feldspar porphyritic rhyolite (TS 47168) at Bastyan Dam (approximately

Fig. 15 Quartz-phyric tuffs, Bastyan Dam.

5378050N, 378050E) has a surrounding zone of weak alteration (mainly silicification) affecting the tuffs and a more extensive zone of quartz - siderite veining, locally to a stockwork, which indicate the rhyolite is more likely intrusive than extrusive.

3.4.3 Rosebery

In the hangingwall of the Rosebery ore deposit, a 200m thick quartz - phyric tuff unit (or epiclastic sequence) overlies Rosebery "host rocks" and equivalents, and is overlain by the Mt. Black Volcanics.

The basal contact of quartz- phyric tuff is demonstrably erosional, as it infills channels or basins of up to 100m stratigraphic thickness in older units. North of the mine one such channel is steep-sided (by interpretation) and has eroded (or filled in an already eroded channel) through black slate and host rocks as it is now in contact with footwall pyroclastics. The erosive nature of the contact is evidenced by abundant black slate fragments especially towards the base of the unit (Fig. 16); several lithic - rich basal breccias are known within the tuffs, indicating a number of repetetive units of common origin.

Most of the rocks sectioned consist of abundant plagioclase and euhedral to embayed quartz in a shard- bearing matrix (Fig. 17)(TS 47144, 47146, 47158, 54793). Clast types include pumice (TS 47145, 54793), feldspar- phyric tuff or lava (TS 47153), spherulitic dacitic lava (TS 47152), amygdaloidal trachytic lava (TS 73R 252.8m), and ill- defined siliceous (TS 47159) and sericite schist (TS47149). Some are crystal - rich with up to 60% quartz and feldspar crystals (TS 47157), which indicates some process of matrix depletion. Brathwaite (1969) points out the presence of discontinuous shale lenses within the "massive pyroclastics".

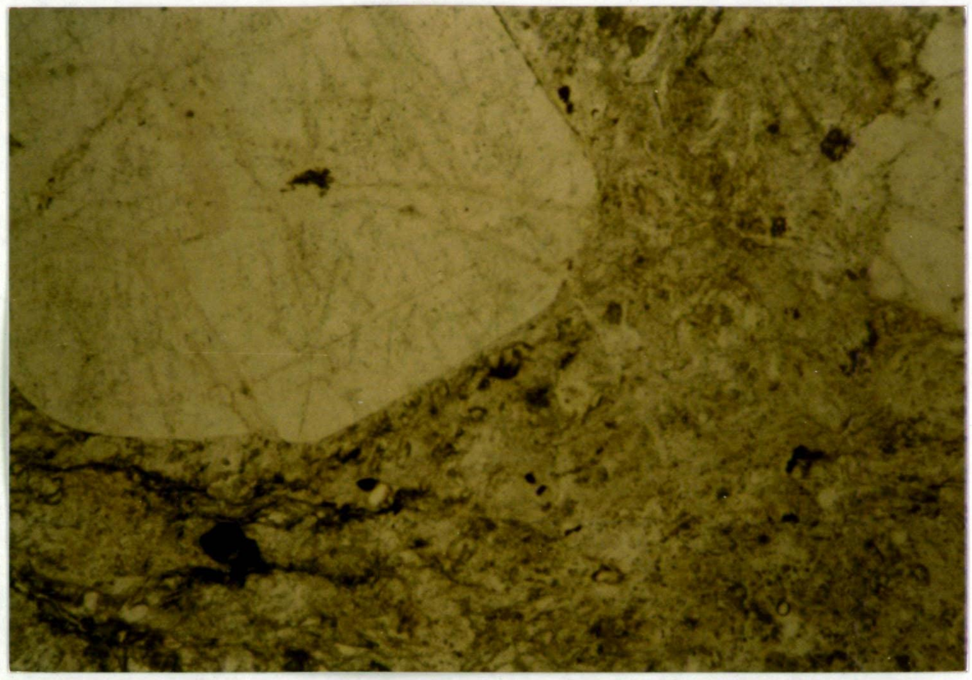
The quartz- phyric tuff sequence is a similar but contracted version of that at Bobadil - Pieman River.

3.4.4 Rosebery Lodes- Dalmeny.

Quartz-phyric tuffs continue southwards from Rosebery to the southern end of Rosebery Lodes, where they pinch out between an altered lava in the host rock position, and massive flow-brecciated lavas of the Mt. Black Volcanics.

Coarse lithic breccias define the bases of several "flows" , and consist of abundant shale and cherty fragments to 20cm length, with quartz and feldspar crystals in a felsic matrix. Breccia grades up into massive tuff with flattened pumice and occasional various lithics such as amygdaloidal spherulitic lava (TS DP 282 122.3m), ill-defined siliceous (TS DP 282 43.2m.), felsic (DP 265 318.1m), quartz- porphyritic tuff or lava (TS DP265 230.8m), and also contains abundant embayed quartz and sericitized plagioclase, in a shard - bearing matrix (TS

Fig. 16 Basal lithic-rich zone, with numerous shale clasts, north of Rosebery (5,376,090N, 378,265E)



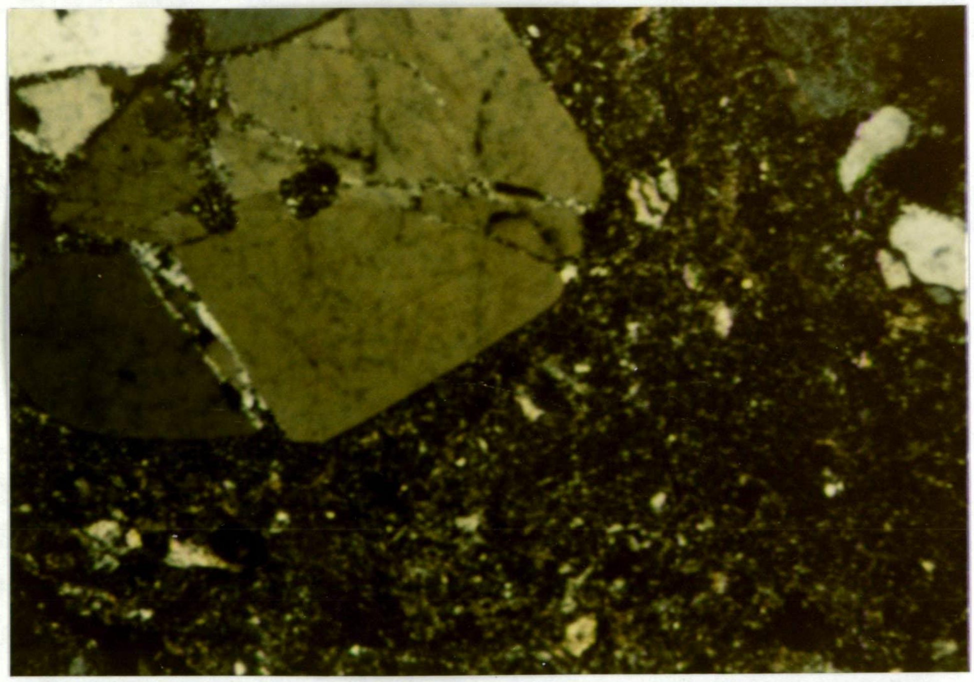


Fig. 17 Photomicrograph of quartz-phyric tuffs, TS 47153
Above, P.P. light; below, X.P. light

1 mm.

DP265 250.8m, 341.1m., RLP 274 67.0m.). A lithic wacke with packed quartz, feldspar and lithics (TS DP 282 300.1m.) is probably a result of matrix depletion through reworking.

Overgrowths of K- feldspar over albitic plagioclase (TS 54513) with a peculiar froth or bubble texture, are described by Solomon (1964), Hall (1967) and Naschwitz (1985). These authors attributed the overgrowths to late volcanic and secondary processes, in agreement with the author's view that they represent a post-emplacement phase of devitrification and crystallization.

A lens of sediments and epiclastics is known from several drillholes in the Dalmeny area, is shown in cross- section (Plan 6). The sedimentary lens consists of reworked tuffs with sericite clasts, quartz crystals/fragments (TS 47163) grading to lithic wacke, and interbedded with volcanogenic sandstone and shale. Two interpretations of this section are viable - a continuous, E-facing sequence with rapid thinning of the tuff between Rosebery Lodes and Dalmeny, and an overturned fold - pair causing a "mirror image" of Rosebery Lodes and Dalmeny.

Evidence supporting a folded sequence is:

- a lithic - rich zone with black slate clasts in the structural footwall of Dalmeny; but reverse grading is known to form lithic- rich tops to flows under a variety of circumstances (Fisher and Schmincke, 1984).

-strongly altered, silicified feldspar - phyric tuffs structurally above the Dalmeny sediments in drillhole DP 259.

Contrary evidence is:

-lack of a third, upright limb, although the limestone in DP 259 is a possible candidate.

-footwall pyroclastics apparently continue to dip E at a moderate angle.

Minor intrusives within the sequence are discussed elsewhere, as is the mineralization at Dalmeny.

3.4.5 Hercules

Mapping shows a more complex stratigraphy in the hangingwall of Hercules. Many units lens out rapidly, and postdepositional faulting has also caused some disruption.

On the north side of the Mt. Hamilton Fault (which terminates the Hercules host rocks and shales) a wedge of coarse lithic breccia with abundant rounded shale and felsic tuff fragments and quartz crystals, overlies relatively unaltered footwall pyroclastics. From here, the trace of the host horizon can be followed north east around Mt. Hamilton, by virtue of sparse quartz phenocrysts and siliceous lithics to distinguish quartz - phyric tuffs from footwall pyroclastics. Quartz gradually disappears up the section so that feldspar - phyric tuffs similar to the footwall pyroclastics occur.

Pelitic to psammitic ash tuffs in the upper Ring River are probably equivalent to host rocks, and are overlain by quartz - phyric tuff. Poor outcrop and intrusives on the west side of the Mt. Read road obscure relationships between the quartz - phyric tuff traced from Hercules, and the Dallwitz - Jones Creek horizon.

At Hercules, the shales are overlain by a thin, discontinuous quartz-feldspar arenite, then altered tuffs with a basal lithic (black slate, shale, pyritic and siliceous fragments) and quartz-bearing zone. This grades into feldspar - phyric, coarsely pumiceous tuff with rare to absent quartz that forms a prominent ridge at Mt. Hamilton.

Another wedge of lithic - rich breccia is present at South Hercules overlying host rocks near where they are truncated by the unconformably overlying White Spur Formation.

A feldspar - phyric, pumiceous tuff overlies shale/ siltstone of the Hercules host rocks and the lithic breccia at South Hercules. It lenses out rapidly, and is replaced by a crystal - vitric tuff with feldspar and minor splintery quartz in a vaguely eutaxitic matrix (TS 55461). Overlying this and the pumiceous tuff is a reworked tuff having a basal lithic rich zone, and consisting of crowded lithics, and quartz and feldspar crystals in a shard-bearing matrix (TS 55473). This grades up into pelitic ash (TS 55500).

A complex sequence is encounted as this pelitic ash is traced southwards from Hercules. A wedge- shaped tuff or lava breccia appears in the sequence. The pelitic ash is closely associated with coarsely pumiceous ?welded tuff (TS 55513), and is present on both sides of it, due to tight folding, and rare facing data from cross-bedding indicates the pelitic ash overlies the ash flow. Laminar and low-angle cross bedding forms are locally well preserved; other areas appear structureless. It contains locally abundant lithophysae (TS 55504, 55520) (Fig. 18) in a finely crystalline, ashy and shard - rich matrix. Close association with probable ignimbrite suggests a genetic relationship (see Sect. 5.2).

On White Spur south of Hercules, feldspar-phyric tuffs stratigraphically above the reworked tuff/ pelitic ash horizon, are identical to these of footwall pyroclastics. Layering, defined by flattened pumice, shows them to strike east- west and dip south.

Coarse pumice to 50cm are common; other lithics are sparsely distributed, and feldspar is ubiquitous. Several thick vitric tuff horizons, probably representing original ash tuff beds, are present.

3.4.6 Dallwitz - Jones Creek

A sequence of quartz - bearing lithic tuffs and shale - siltstone - pelitic ash extends from the Dallwitz prospect south to at least Jones Creek. Mapping by K. Corbett shows it to extend south to Howards Road near the North HFZ. Intrusive quartz - feldspar porphyry complicates and obscures the western margin; while flow - brecciated lavas outcrop to the east.

Fig. 18. Lithophysae, South Hercules (5365380N, 376900E).

Relationships with the sequence traced north- east from Hercules are uncertain; because of the intrusive and poor outcrop. The reasons for placing the Dallwitz - Jones Creek sequence above, and truncating parts of the host and hangingwall sequence, are:

- No closure of fold nose is evident; the sequences appear to merge.

- The lavas (?overlying) east of Dallwitz - Jones Creek correlate with those at Rosebery - Lodes - Dalmeny.

- Although folds are known within the shale- siltstone pelitic ash horizons, rare facings in Jones Creek drill holes are to the east (I. McDonald, pers. comm.).

North of Dallwitz, poor exposure prevents relationships between Rosebery Lodes - Koonya and Dallwitz - Jones Creek being established.

Predominently west dips within the shale siltstone - pelitic ash along the entire strike, and lack of unequivocal facing data, mean that a syncline can be interpreted between the Hercules host rock and Dallwitz-Jones Creek horizon. This idea, shown in Green 's (1983) map, is unlikely as there appear to be no break or fold closure in the Dallwitz - Jones Creek horizon.

Lithic tuffs of the Dallwitz - Jones Creek horizon are extremely variable in grainsize, rounding and sorting characteristics. Lithic breccia, with coarse (to 20 cm) lithics and pumice, or abundant medium-grained lithics and crystals in a depleted matrix, are common. Clast types include siliceous, silicified pelite, chert (TS 55431, 55563), lithic wacke, felsic lava (TS H704 894ft.) also shale, black slate, and amygdaloidal lava (silicified basalt?). Crystals of both quartz and feldspar are common, and shards are often present in the matrix (TS 55431).

Sediments vary from tuffaceous sandstones to pelitic ash siltstone (TS 55421).

Minor amygdaloidal basalt (TS 55425) is present in a discontinuous series of pods.

3.4.7 Synopsis

A number of features common to the quartz- phyric tuffs sequences from Bastyan Dam to Rosebery Lodes suggest a common origin for a number of "flows" recognized within the sequence. General features of the "flows" are shown in Fig. 19, comprise:

- open framework (matrix supported);
- basal lithic- rich breccia, usually with shale, slate and siliceous lithics, which grade with decreasing size and abundance of lithics into the following;
- homogeneous tuff with quartz and feldspar crystals and scattered lithics, and
- reworked tuffs showing some bedding and often grading into a sediment/ epiclastic sequence of sandstone, siltstone and shale, at the top of the unit.

Clast types including amygdaloidal andesitic/ basaltic lava, as well as the expected accidental lithics of underlying rock types such as black shale, show the flows have travelled some distance across a variety of lithologies. Shards are generally well preserved, which

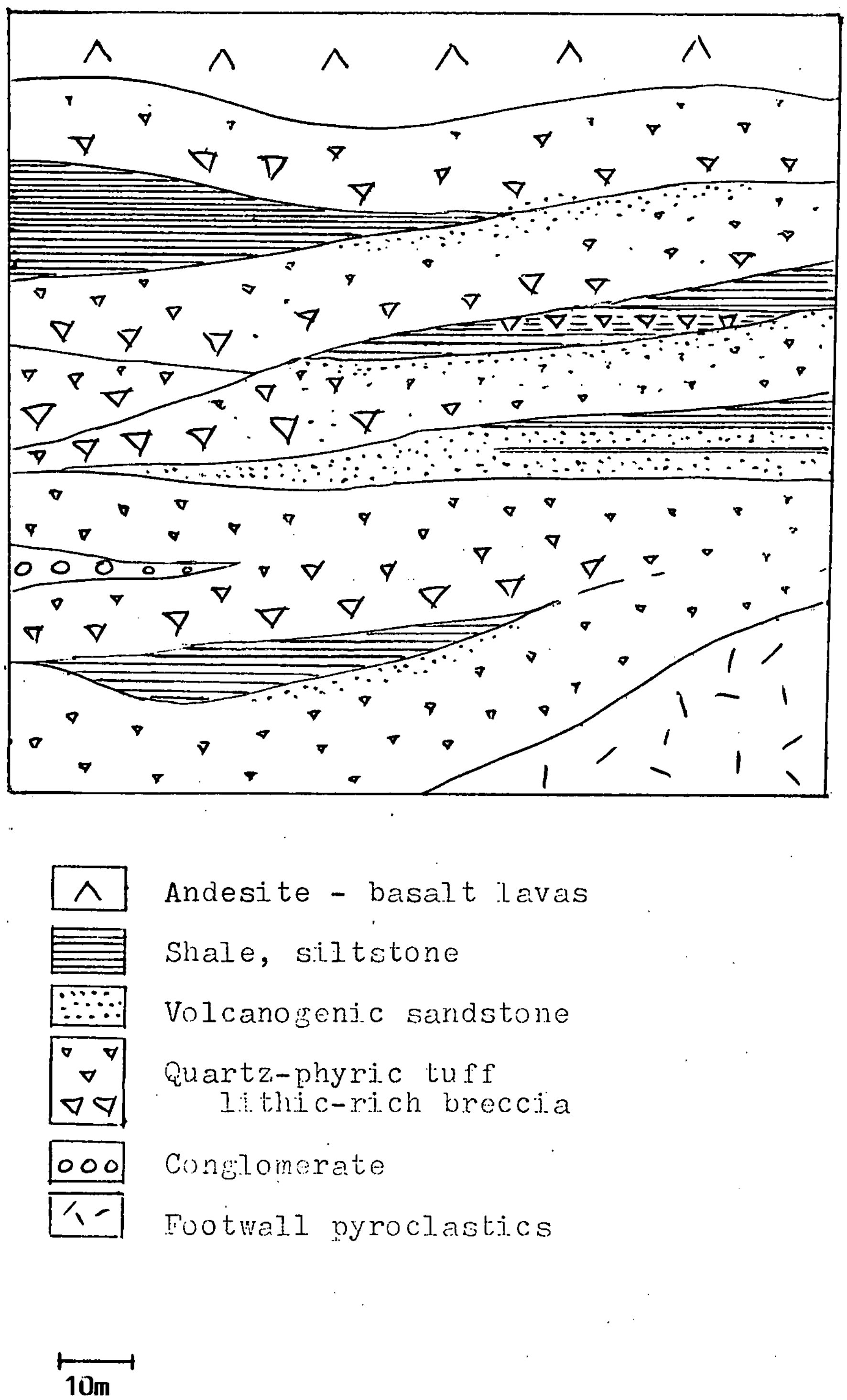


FIGURE 19 - General features of quartz-phyric tuff sequence north of Rosebery

indicates little or no elutriation.

Thickness of these units varies from approximately 10 m., to over 100 m. at Bastyan Dam. These features suggest emplacement as coherent mass flows largely of volcanic material but including a substantial "accidental" sedimentary component.

Shale-hosted " lithic breccias" (described in Section 3.5.2) are attributed to mass flow processes, where by (?primary) volcanic material is transported *en masse* downslope and incorporated within contiguous argillites as a lithic breccia.

Although the environment of deposition is subaqueous and probably submarine, it is likely that some of the flows were originally pyroclastic, but were deposited below welding temperature. Some of the thicker units near Hercules still have the diverse lithic assemblage at the base, but grade up into felsic tuff with abundant pumice that appear to be welded (i.e. fiamme) in places. Overlying is a mixed sequence of epiclastics and siltstones in the Dallwitz-Jones Creek area.

The appearance of quartz crystals exactly at the ore postion within the host rocks at Rosebery, and just above Hercules host rocks, and their continued presence through the succeeding epiclastics and tuffs cannnot be attributed solely to the epiclastic process bringing in material from a quartz- bearing provenance, as all the exposed footwall is devoid of quartz phenocrysts. Possible reasons for the appearance of phenocrystal quartz at this point, accompanying ore formation and a change mode of deposition of the volcanics, will be discussed later (Sect. 7).

3.5 MT. BLACK VOLCANICS

3.5.1 Introduction

The Mt. Black Volcanics (Brathwaite, 1969) overlie the quartz - phyric tuffs, and consist of massive, flow - banded and flow - brecciated lavas of generally dacitic to andesitic, and rarely rhyolitic, composition. Probable hyaloclastite lavas are present, also minor tuffs and sediments, and various intrusives.

Green (1983) recognised a lower unit of flow - banded and autobrecciated rhyolite to dacite lavas, and an upper unit of dacite, andesite and minor basaltic tuff and lava.

3.5.2 Andesite-Basalt

A wedge of distinctively mafic andesite to basalt lavas are present north of Rosebery and extend to Bastyan Dam. Drillhole 71R gives a section through the base of this sequence, and from this it can be concluded that the basal contact is east-dipping and grossly conformable with the underlying tuffs and sediments.

The lavas are apparently quite homogeneous, consisting of coarse chlorite laths in a granular felsic matrix in hand specimen. In thin section, the chlorite clots contain relict patches of a mineral with high birefringence (pyroxene?) which occur in a silicified felsic groundmass with a network of chlorite veins (TS 47156). Near the western margin, similar chloritized mafic phenocrysts are present along with zoned amygdales having quartz cores and chlorite rims (TS 55570)(Fig. 20) and similarly textured rocks are seen in drillhole 71R . Occasional strongly chloritized areas are found within the sequence, and may represent chilled, altered margins of flows, or thin, altered basalts. Various breccia -textured rocks are present in 71R, having chloritic and siliceous fragments in a strongly chlorite - quartz - pyrite - carbonate veined matrix. S. Joyce (written comm.), describes a hydrothermal breccia, which is probably similar to those logged in 71R. Magnetite is a common accessory, also occuring in quartz - magnetite - pyrite veins in drillhole 71R, contributing to a large aeromagnetic and ground magnetic anomaly centred on the andesite - basalt.

The southern margin of the andesite - basalt is strongly silicified (TS 54697) and pyritic in places, and difficult to distinguish in hand specimen from nearby felsic volcanics, but relict chlorite patches after mafic phenocrysts remain in some altered lavas (TS 54775).

Minor sediments and epiclastics have been mapped overlying the andesite - basalt, and are succeeded by massive dacite lavas. Green's (1983) map shows a small sediment lens or raft near the collar of drilldole 71R.

3.5.3 Massive Dacite Lavas

A thick sequence of massive flow-banded to flow-brecciated dacite to rhyodacite and rarely rhyolite lavas extends from Mt. Black to south of Mt. Read.

Although a wide variety of textural types are present, much of the dacite consists of massive, textureless or vaguely flow-banded felsic lava with feldspar crystals (TS 47143, 47160, 55759), in an often spherulitic matrix (TS DP 259 86.5m., 54969, 55566). Lava breccias, including probable hyaloclastite types, usually form the basal 100m or so of the lava. These consist of fine- grained, chilled aphanitic lava fragments, streaky sericitic fragments resembling pumice, and grading to sericitic flow-streaks which merge into a felsic, sometimes flow-banded matrix with scattered feldspar crystals (TS 47161, 54302, 73R 170.3m, DP 259

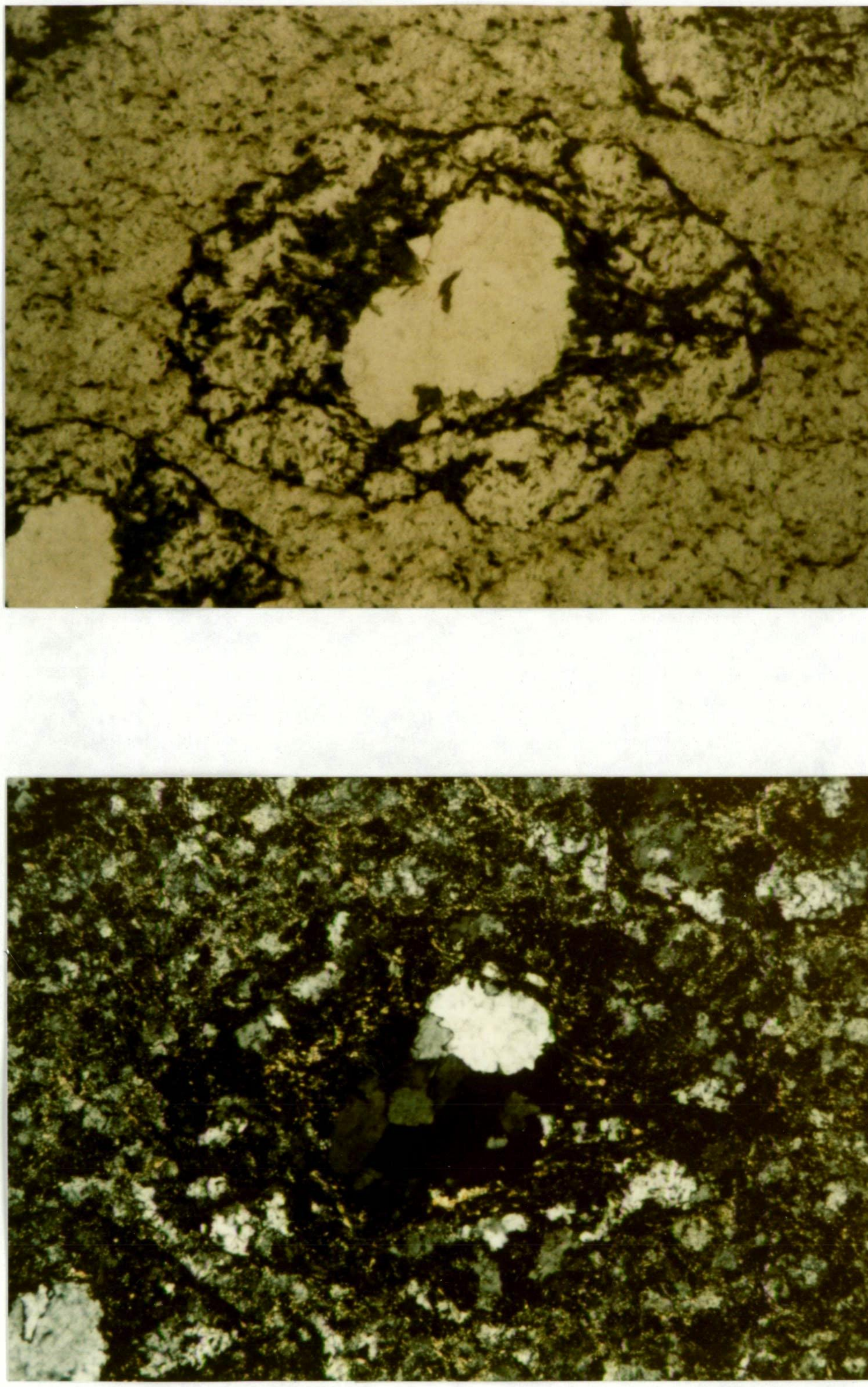


Fig. 20. Photomicrograph of quartz-chlorite amygdales in andesite lava, TS 55570. Above, PP light; below, XP light.

1mm

128.7m, DP 259 141.3m, RLP 274 43.3m, RLP 275 88.8m) (Figs. 21, 22).

Quartz crystals are present in a few rocks that may well be lavas, indicating that minor rhyolites occur, but some of those mapped as lavas may be intrusives. Probable rhyolite extrusives are represented by quartz-bearing spherulitic lava (TS 54939) and quartz-feldspar bearing rhyolite (TS DP 259 43.5m.).

Good exposures on Mt. Read show a number of textural types. The western, stratigraphic base of the lavas contain coarse flow-breccias, usually with coarse fragments of flow-banded lava in a felsic matrix. These pass into probable hyaloclastites along the Mt. Read road and northern ridge of Mt. Read, consisting of sericitic pumice-like streaks, some with distinct outlines and others merging into the feldspar-phyric, lava-like matrix (TS 55584, 56094)(Figs. 23, 24). Further east are beautifully flow-banded lavas (Fig. 25) and flow-brecciated lavas, with numerous granophyric to porphyritic quartz-feldspar-phyric intrusives (eg. TS 55416), forming an integral part of the sequence.

3.5.4 Andesite Lavas

A series of intermediate (mainly andesitic) lavas with minor felsic lavas and tuffs, is well exposed on the Murchison Highway east of Rosebery, and in the upper Stitt River.

Andesite lavas forming the bulk of this sequence contain feldspar and chloritized mafic phenocrysts (?amphibole) (TS 55028, 55571) in a variably altered groundmass. One particular trachy-basalt with calcite amygdales (TS 54728, 54729), can be traced for two kilometres in sparse outcrop and from detailed ground magnetic data. Minor dacites (TS 55566) and flow-banded rhyolite (TS 55042) are also present.

The top part of drillhole RLP 275 penetrated the base of this andesitic lava sequence, and shows a complex mixture of andesite and hyaloclastic dacite lavas. The two types, dacite lava of chilled silicified lava fragments in a flow-oriented feldspar-phyric felsic matrix, and andesite of plagioclase laths in a chloritic matrix, alternate in one to two metre bands over tens of metres.

3.5.5 Sediments

A number of sedimentary lenses are known within the Mt. Black Volcanics.

Thin limestones, although discontinuous and not outcropping, are widely distributed and occur at Dalmeny in drillholes DP 5 and DP 259, near the base of the lava sequence, and in several drillholes above the northern end of Rosebery. At Dalmeny, the limestone consists of fine, banded calcite with silt-sized quartz (TS DP 259 161.5m.) with a basal hematite-talc altered zone (TS DP 259 180.2m.), while east of the Rosebery mine, finely banded carbonate (mainly calcite) and quartz (TS 47150) contains sericitized tuffaceous lithics, and occurs within

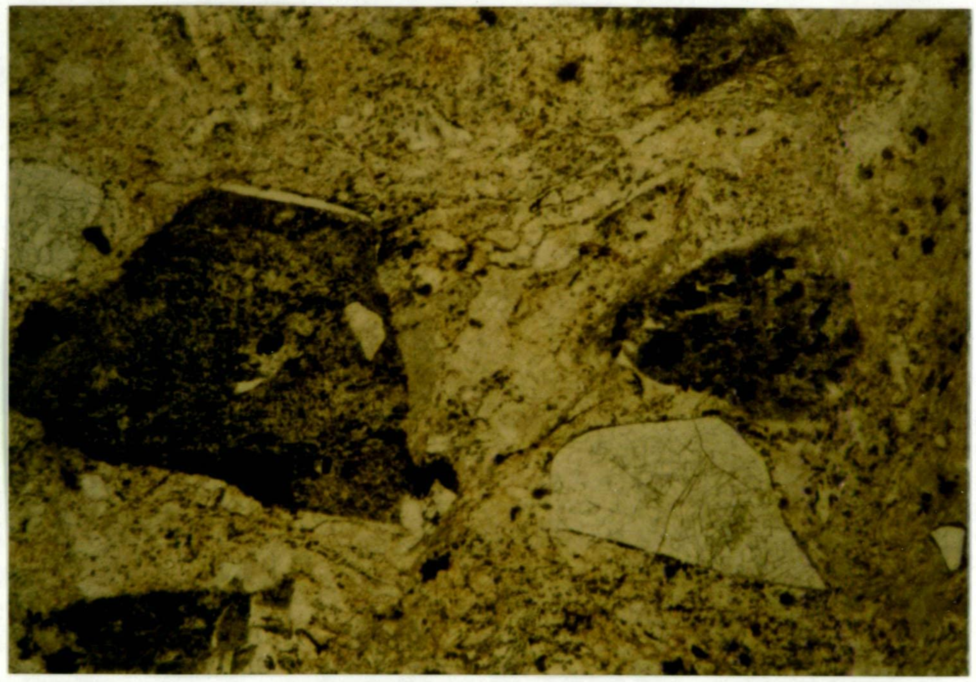
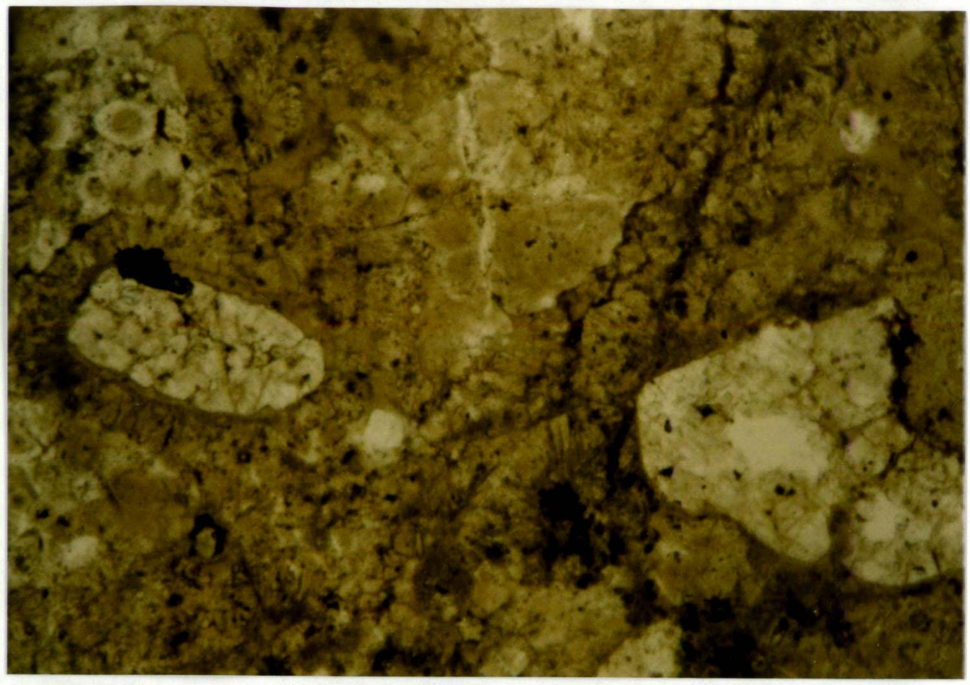


Fig. 21. Microphotograph of hyaloclastite lava, TS 54513.

1mm



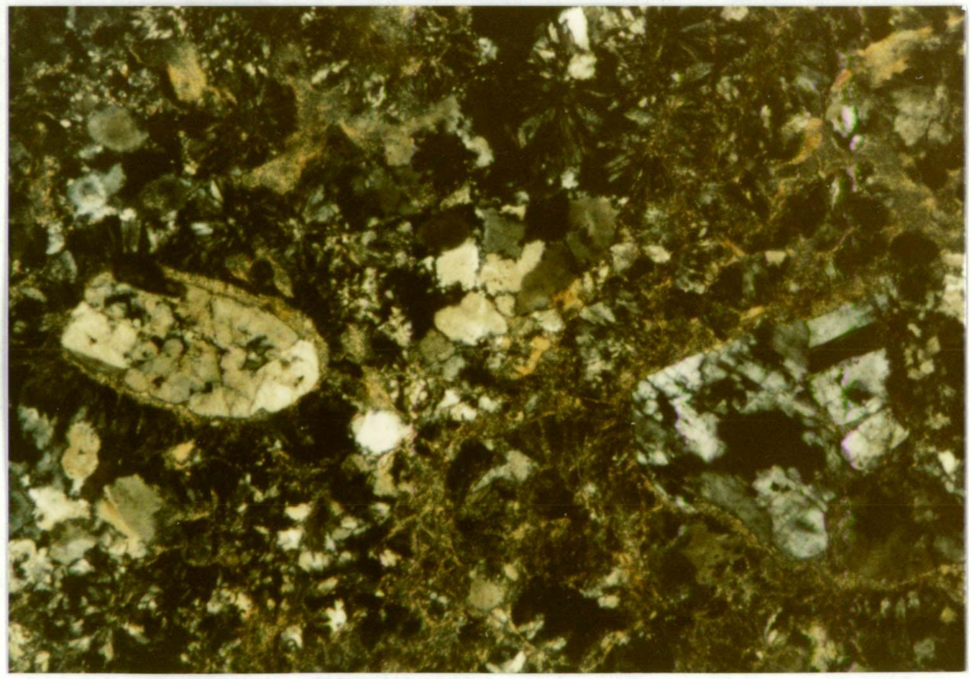


Fig. 22. Photomicrograph of hyaloclastite lava, TS 54969.
Above, PP light; below, XP light.

1mm

Fig. 23. Hyaloclastite lava; pulled-apart fragments of fine-grained lava in porphyritic lava matrix, Mt. Read Rd (5367100N, 377680E).

Fig. 24. Flow-banded, brecciated hyaloclastite lava, Murchison Highway.

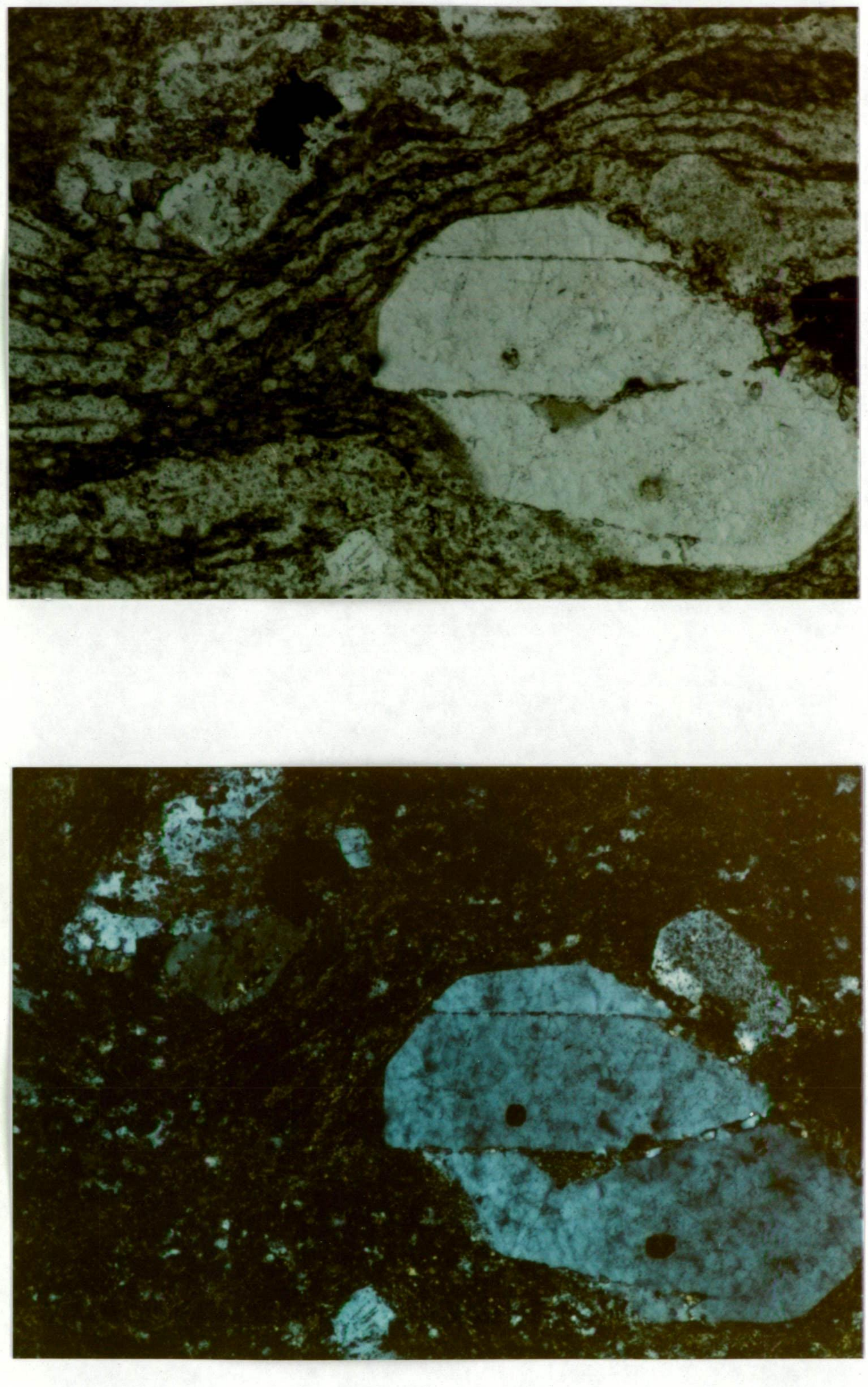


Fig. 25. Photomicrograph of flow-banded porphyritic lava, TS 55042.
Above, PP light; below, XP light.

1mm

a wedge of tuffs in the flow-brecciated dacites. Epiclastic tuffs composed of various lithics in a silt-sized matrix, occur along strike of the extrapolated position of the limestone. Nearby tuffs are coarsely pumiceous feldspar-phyric agglomerates, apparently devoid of quartz crystals.

Poorly bedded epiclastic "crystal tuff" with variable proportions of feldspar crystals, chloritic and tuffaceous lithics (TS 56089) occurs within massive dacitic lavas and minor tuffs east of Rosebery.

K. Corbett (pers. comm.) reports a shale lens about 1km east of Mt. Read, presumeably within the lava sequence.

3.5.6 Synopsis

A massive sequence of dacite and andesite lavas overlies the quartz-phyric tuffs. North of Rosebery, a thick wedge of andesite and minor basalt lava and lava-breccia are followed by tuffs and epiclastics at the base of the massive dacite lavas. These extend at least from the Pieman River to Mt. Read and then south and east to the HFZ, and consist of multiple flows with basal flow-breccias and hyaloclastites succeeded by massive and flow-banded types. Minor tuffs and sediments, including limestone, are present.

Between 500 and 2,000 m of dacites are followed by thick andesites with minor basalts, dacites, rhyolites and tuffs, that apparently continue eastwards to Tullah (based on EZ Co. mapping), where the shale-sandstone-epiclastic tuff-basalt sequence running parallel to the HFZ is present. This would imply a total thickness of some 4,000 m of lavas in a continuous E-facing sequence.

3.6 DUNDAS GROUP

3.6.1 Introduction

The term "Dundas Group" can be traced to Hills' (1915) "Dundas Slates and Breccias" west of Rosebery. Finucane (1932) regarded the slates, quartzites and breccia-conglomerates of the "Rosebery Series" as underlying the slates and mafic breccias of Ordovician "Dundas Series". Elliston (1954) defined the Dundas Group at Dundas as a thick sequence of greywacke, slate, conglomerate and minor tuff unconformably overlying the Carbine Group (Precambrian). Banks (1956) essentially followed the work of Elliston. Solomon (1960) included the Mt. Read Volcanics of the Queenstown area in the Dundas Group, as the volcanics also overlie the Precambrian Carbine Group. Campana and King (1963) considered the Dundas Group to have been deposited in the post-Mt. Read Volcanics Dundas Trough, and to consist of initially argillites, slates and chert (the Crimson Creek Formation of other workers), then greywacke, mudstone and conglomerate. Solomon (1965) placed the "Rosebery Series" below the Mt. Read Volcanics, and considered them to be overlain by Crimson Creek Argillite then Dundas Group, both largely coeval with the volcanics. Loftus-Hills et al. (1967) modified that view by equating the "Rosebery Series" with the lower part of the Mt. Read Volcanics. Brathwaite (1970) also considered the Crimson Creek Argillite to conformably overlie the Rosebery Group. Solomon and Griffiths (1974) suggested that the Crimson Creek Formation and unconformably overlying Dundas Group were both in part coeval with the Mt. Read Volcanics. Green et al. (1981) also regarded the Rosebery Group as coeval with the volcanics, having been deposited in a marine basin adjacent to the volcanic arc, and overlain conformably by the Crimson Creek Formation. Green (1983) studied the Rosebery Group in detail, and re-interpreted the stratigraphy within the Rosebery Group as a series of fault slices with some tectonic slides separating units.

The Dundas Group has recently been redefined (Corbett and Lees, in press) to include the epiclastic tuff and sediment dominated White Spur Formation at the previously undefined base of the formation, which is seen to overlie Central Sequence volcanics unconformably. The relationship of Dundas Group rocks to the Crimson Creek Formation in the belt west of the volcanics, cannot be determined directly, as contacts are always faulted (Brown, 1982; K. Corbett, pers. comm.) but most workers regard the Dundas Group as stratigraphically younger than the Crimson Creek Formation (eg. Adams et al., 1985). The faulted contacts, often with ultramafics or gabbro in the Crimson Creek Formation adjacent to the faults, imply tectonic upthrusting and emplacement of the Crimson Creek Formation into the Dundas Group.

3.7.2 White Spur Formation

The White Spur Formation at the base of the Dundas Group unconformably overlies Central Sequence volcanics.

In the mapped area, the White Spur Formation is present west of Rosebery in a wedge bounded to the east by the Rosebery Fault and to the west it is overlain conformably by the Stitt Quartzite. It reappears on the east side of the Rosebery Fault south of Jupiter; from there to Williamsford is present as a fault - bound sliver, then it gradually widens onto White Spur.

Deep drilling at Rosebery shows the White Spur Formation to be present at least 1.5km down- dip of the Rosebery Fault, giving a stratigraphic thickness of at least 2,000m, which includes about 300m of the Chamberlain Shale member at the top of the formation. In the Howards Road area, work by K. Corbett indicates a thickness of approximately 3,500 metres.

The base of the White Spur Formation can be traced from Williamsford to Howards Road. Coarse lithic- rich breccia usually occurs at or near the base of the formation, overlying thin shales at West Hercules and intebedded sandstones and shales further south at (5364000N, 376120E). The lithic breccia consists of various matrix- supported lithics often to 50cm and rarely 1-2m diameter, subrounded to angular, and consisting of shale, slate, felsic tuff, chert, pumice and occasionally massive pyrite or sphalerite - bearing siliceous types. Quartz and feldspar crystals are present within a felsic matrix.

The coarse lithic breccia often grades into lithic - crystal tuff, with occasional smaller lithics of various types, quartz and feldspar crystals. Reworked tuff and poorly bedded lithic wacke (TS 55547) and volcanogenic sandstone (TS 55464) occur at the top of the "cycle" and are overlain by shale, pelitic ash (TS 55508) and sandstone that can be traced for several kilometres and define large folds. A second relatively thin unit of crystal - lithic tuff with basal lithic- rich breccia overlies the sediments, and is followed by pelitic ash, and a third, thick tuff with coarse basal breccia which grades into massive tuff with sparse lithics, feldspar and occasional quartz crystals. Interbedded shales, volcanic sandstone and pelitic ash follow, at the top of the sequence exposed in a syclinal structure.

Complex structure between White Spur and Bather Creek makes interpretation of this part of White Spur Formation difficult; the interpreted section is shown in Plan 7.

Overlying the tuff- rich sequence, is a sediment - dominated shale- siltstone- greywacke succession with minor tuffaceous lithic wacke bands. This sequence forms the core of a syncline extending from Bakers Creek southwards to at least Howards Road, and consists of greywacke- siltsone and minor shale often graded beds from a few millimetres to several metres thick, and show basal scour and flame structures, graded bedding, rare convloute bedding in argillaceous beds, and laminated shales between the graded greywacke beds.

The Rosebery Fault, and a number of sub-parallel secondary faults, disrupt the White Spur Formation. The Chamberlain Shale Member, at the top of the White Spur Formation, is present west of Rosebery.

<u>Chamberlain Shale Member</u>

The Chamberlain Shale (Brathwaite, 1969) outcrops west of Rosebery in the Stitt River and along the Flume Road. It has been recently re-defined as the top unit of the White Spur Formation (Corbett and Lees, in press).

At Rosebery, interbedded shale, siltstone, greywacke and lithic wacke, similar to those described above from White Spur, pass conformably (westwards) to 300m of west diping and west- facing laminated shale with minor siltsone, and thin pyritic bands.

In the Pieman River gorge, a tectonic breccia of rolled, contorted sandstone balls in a crumpled slatey matrix is deformed Chamberlain Shale in fault contact with the Mt. Read

Volcanics. A similar faulted contact occurs in drillhole BD1, but the shales and slates are less deformed in BD269 further south.

In the Bodadil area, the shale is 50 - 60m thick, and is present underneath the Mt. Read Volcanics because of the Rosebery Fault dipping east at about 40°. Bedding dips steeply west to east, although limited facing data is to the west. The Chamberlain Shale consists of laminated shale - siltstone with minor thin sandstone beds, is locally graphitic and has very fine grained semi - massive pyrite in thin bands over several metres. The formation change to Stitt Quartzite occurs suddenly but conformably when graded sandstone- siltstone beds dominate over siltstone-shale.

A thin shale is commonly present between the Mt. Read Volcanics and Stitt Quartzite north of Jupiter Mine and south of Williamsford, and is probably equivalent to the Chamberlain Shale.

3.6.3 Stitt Quartzite

Conformably overlying the Chamberlain Shale Member at Rosebery is the Stitt Quartzite, originally described by Campana and King (1963). It extends from the Jupiter Prospect, where it is truncated by the Rosebery Fault, northwards at least as far as the Pieman River. Green (1983) drew attention to a lithogically identical unit, mapped in D. Jennings in Collins et al. (1981), in the Hatfield River some 20km north of the Pieman River, in a sequence similar to the "Rosebery Group".

In the Jupiter- Pieman River section, the Stitt Quartzite is about 400m thick and consistently faces west although dips vary form east (overturned) in the Pieman River gorge, to west along the Pieman River near Rosebery, and locally east at Jupiter close to the Rosebery Fault. Figure 26 shows W- dipping and W-facing interbedded sandstone and shale, typical of much of the Stitt Quartzite.

Two main facies (also recognized by Green, 1983) are present; a thick - bedded, massive well- sorted micaceous quartz-arenite to quartzite with thin argillaceous (now shale- slate) bands, and a thin - bedded to laminated shale - siltsone - sandstone facies that often forms the top 50 to 100 metres of the unit, and also may be present near the base where the Chamberlain Shale grades to Stitt Quartzite.

Massive quartzites, to several metres, may have scoured bases and contain little internal stratification. These massive beds occur within well bedded sandstone- minor siltstone- shale that contains graded bedding, sole marking, occassional ripple markings, and rarely convolute bedding. Green (1983) draws the obvious analogy with an A, AB, or ABC Bouma sequence, but ABCD Bouma sequence is occasionally present.

Green (op. cit.) described the petrology of Stitt Quartzite lithogies as quartz wacke, quartz

Fig. 26. Stitt Quartzite on Flume Rd. (5374750N, 377330E), W dipping and facing.

Fig. 27. Siliceous conglomerate, Pieman River gorge (5377180N, 376000E).

arenite, siltstone and slate with a few conglomerates , and noted that the grains were mainly of quartz but include quartzite, quartz-mica schist, phyllite and muscovite.

The thin-bedded shale-siltstone-sandstone facies commonly shows graded bedding, fine ripple cross-lamination, and laminar bed forms. The author agrees with Green's (1983) recognition of BCD, BC and CD Bouma sequences.

Units lithologically similar to the Stitt Quartzite, composed of quartz arenite, siltstone and shale or slate (the "Munro Creek Slate and Quartzite" of Campana and King (1963) and others), occur in a meridional belt in the Pieman River west of the Stitt Quartzite proper and at Williamsford and the Ring River. Green (1983) correlated the Munro Creek Formation with the Stitt Quartzite, now additional structural and stratigraphic evidence confirms this idea.

The western exposure of Stitt Quartzite in the Pieman River gorge, formerly "Munro Creek Slate and Quartzite", or "Munro Creek Formation " of Green (1983), consists of 200 m. of deformed, melange - like quartzite and slate, with a complex, fault-bound western margin and disrupted eastern margin. A siliceous conglomerate, 1-3m thick of coarse quartzite, siliceous and shale fragments in siliceous sandy matrix (Fig. 27) occurs close to the western contact. The remainder of the unit is of deformed interbedded sandstone to quartzite arenite, and siltstone shale to slate, but this is often present as a tectonic melange of quartzite fragments or boulders in a slate matrix (Fig. 28). Facings in the units are variable.

In the Williamsford - Ring River area, a number of fault - bound slices of interbedded quartz - arenite, siltstone, shale and slate are analogous to the Stitt Quartzite, showing typical Stitt Quartzite lithofacies of massive quartz - sandstone beds, and interbedded sandstone- minor shale. Dips vary considerably, and melange-like zones, similar to those in the Pieman Gorge, are present (Fig. 29).

3.6.4 Westcott Argillite

The Westcott Dolomitic Beds (Campana and King, 1963) is the name for dolomitic siltstones in the Pieman River west of the Salisbury Conglomerate, and on Westcott Hill (also Westcott Beds of Loftus-Hills et al. (1967), Westcott Argillite of Brathwaite (1969), and Green (1983)).

Westcott Argillite outcrops in the Pieman River, the Natone Creek area, the Ring River, and the Moores Pimple area. The typical lithology is massive dolomite and laminated dolomitic shale and siltstone beds (Fig. 30), but dolomitic wacke of sand-sized quartz, shale and other grains in a dolomitic matrix is common. Minor limestone is also present.

A transition from Stitt Quartzite to Westcott Argillite is seen in the Pieman River near 5378050N, 377000E, which is also described by Green (1983). Massive quartz- arenite with

Fig. 28. Tectonic melange of quartzite blocks in slatey matrix, Pieman River gorge (5377300N, 376105E).

Fig. 29. Tectonic melange of disrupted quartzite and shale, Williamsford (5368240N, 375580E).

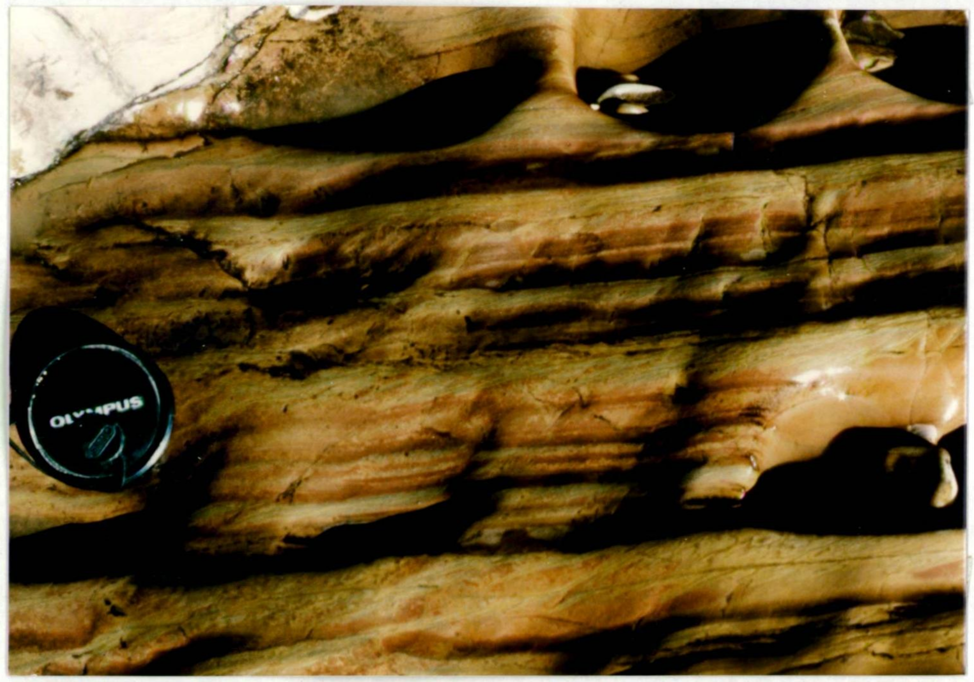


Fig. 30. Laminated dolomitic siltstone of Westcott Argillite, Pieman River gorge (5377400N, 376350E).

Fig. 31. Salisbury Conglomerate, of sandstone, siltstone and fuchsitic clasts in dolomitic matrix, Pieman River (5376430N, 376400E).

interbedded shale, typical of Stitt Quartzite gives way to laminated dolomitic siltstones still with occasional quartz-wacke and quartz-arenite beds, then dolomites, silty dolomites and dolomitic siltstones that comprise the bulk of the unit. Flame structures are common in this interval.A number of thin conglomerates form a mappable unit, and define a major syncline. Green (1983) records clasts of chert, dolomite, quartz, and quartzite, and grains of mafic volcanics. Although a similar clast assembly to the Salisbury Conglomerate is present, there are several important differences, such as the open framework and fine silty matrix, which indicate this conglomerate is intraformational. Approximately 150 m of dolomitic sediments and conglomerate is present here.

South west of the synclinal closure, the Westcott Argillite is repeated in a now east facing sequence, but a break in outcrop separates these from a mainly east facing laminated shale - siltstone - quartz wacke unit, probably the laminated Stitt Quartzite facies. A further section of east facing Westcott Argillite is exposed west of the laminated shale - siltstone - quartz wacke, and consists of 200 m of dolomitic wacke and minor laminated dolomitic siltstones, and culminates in 15 m of Salisbury Conglomerate.

A minimum thickness of 350 m for the Westcott Argillite is obtained from the two sections in the Pieman River, as these are regarded as non-overlapping. Extensive dolomitic wacke and dolomitic siltstone in the Ring River south of Williamsford show strong local disruption and faulting.

3.6.5 Salisbury Conglomerate

The Salisbury Conglomerate (Brathwaite, 1969), also breccia- conglomerate of Finucane (1932), fuchsite breccia- conglomerate of Campana and King (1963) and fuchsitic conglomerate of Loftus-Hills et al. (1967) outcrops in the Pieman River gorge, Natone Creek - Pieman River bend, on the Williamsford Road, and in the Moores Pimple area.

Thickness of the unit is variable, from 5 to 100m, and a number of distinct conglomerate units are often present. Interfingering with the Natone Volcanics is seen along the Williamsford Road, in Natone Creek, and the Department of Mines Natone Drillhole (see Green, 1983). In the Pieman River gorge the Salisbury Conglomerate conformably overlies Westcott Argillite.

The conglomerate is a clast- to matrix - supported, polymictic conglomerate with usually a dolomitic or rarely cherty matrix comprising to 50% of the rock. Clasts are often well rounded, to subangular, averaging 5-10cm rarely to 30cm, and consist mainly of chert, quartzite, grey to black shale and slate, less commonly carbonate (including dolomite), phyllite, fuchsite, mafic volcanics (including tholeittic dolerite, described in Green, 1983)(Fig. 31). Green (1983) also noted felsic volcanic clasts.

3.6.6 Natone Volcanics

The Natone Volcanics (Campana and King, 1963) outcrop in the Natone Creek- Pieman River bend area, and on the Williamsford road to near Jupiter where they are truncated by the Rosebery Fault. The Natone Volcanics are apparently absent in the Pieman River gorge.

The tuffs are cleaved and sericitized vitric - crystal - lithic tuff, recognisable as a number of flow units north of Jupiter where conglomeratic pebble bands are present. Small lithics of shale, siltstone and chert are commonly present (TS P4), also pumiceous lithics, quartz and sericitized feldspar phenocrysts (TS P1) in a strongly sericitic matrix. Green (1983) reports shards from one thin section .

The flow banded, flow brecciated quartz - porphyritic rhyolite lava or intrusive within the Dundas Group on Moore's Pimple, is closely spatially associated with the Salisbury Conglomertate. Near the southern termination of the quartz - porphyry are some unusual breccias, consisting of medium to coarse angular quartz - porphyry fragments, also sparse shale and slate fragments, in a shaley matrix. The same lithologies were recently intersected in the Department of Mines Moores Pimple drillhole. Massive porphyritic rhyolite grades into breccia of shale - filled crevices which widen and often themselves contain a breccia of altered lava fragments (Fig. 32). Margins of these fractures often have a rind of banded, altered lava, which may be a result of quenching. A different but related breccia consists of coarse rounded to angular porphyritic rhyolite and altered felsic (rhyolite?) fragments, and a few sedimentary fragments, in a shale matrix (Fig. 33). An interpretation of these rocks is given in Sect. 5.8.

3.7 INTRUSIVES

A number of quartz - feldspar - phyric porphyry intrusives are known within the footwall pyroclastics in the Rosebery area, and are widespread south and east of Hercules. Granophyres appear to be confined to the Mt. Black Volcanics where they are common.

Quartz-bearing Intrusives

Several small intrusives near Rosebery consist of embayed quartz phenocrysts and sericitized feldspar in weakly flow-banded quartzo - feldspathic groundmass (TS 54911). Similar rocks are present at Koonya and Chamberlain, already described in Sect. 3.3.6.

A number of larger intrusive bodies occur from Hercules to Mt. Read, and vary in texture from porphyritic to granophyric, but are characterized by having feldspar and subordinate quartz crystals (TS 55371, 55416, H704 244', H704 375'). Some bodies have obviously

Fig. 32. Rhyolite lava breccia, Moores Pimple drillhole.

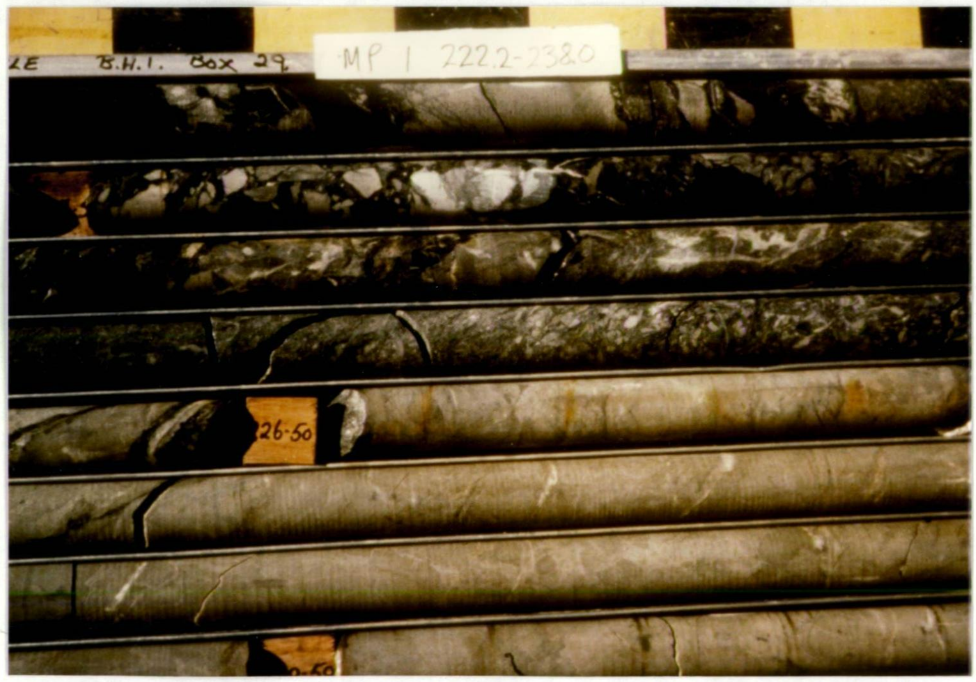


Fig. 33. Sediment- hosted breccia adjacent to rhyolite lava-breccia, Moores Pimple drillhole.

intrusive relationships, and several are traceable over a kilometer or more.

Granophyric Intrusives

Granophyres are fairly common in the Mt. Black Volcanics east of Rosebery, and consist of packed albitic plagioclase crystals, sparse chlorite flecks (after mafic crystals), in a sparse sericitic matrix (TS 54621, 54664, 54945, 55567). Graphic textures are sometimes present (TS RLP 275 226.0m.), as is micro-breccia texture (TS 54947). Field relationships show several of these granophyres in the Mt. Read area are obviously intrusive, as they cross-cut the strike of other units, and branch in several places.

Gabbro

Several gabbroic bodies occur in the area, and with one possible exception, are confined to the west side of the Rosebery Fault, and have a close spatial relationship with the Westcott Argillite and/or Crimson Creek Formation. The possible exception is a coarse mafic rock from Jones Creek (5364850N, 377900E) which is composed largely of plagioclase and pyroxene. This may be a larger and therefore coarser- grained equivalent of the dolerites discussed below.

Two gabbro bodies occur on the north and west sides of Moores Pimple. The margins are strongly carbonate - fuchsite - silica altered for up to tens of metres, retaining only relict ilmenite grains in either massive carbonate or quartz- veined carbonate - fuchsite matrix, in the most strongly altered rocks. Relatively unaltered gabbro consists of pyroxene and plagioclase in a felsic matrix. Some ultramafic variants, including serpentinite, have been reported from this area (EZ Co. internal reports).

Thin, dyke-like gabbro outcrops in the Ring River (5366950N, 375010E), on the North-east Dundas Tramway (5367240N, 375180E), and in the Pieman River gorge (5377140N, 375990E), within dolomitic sequences. These consist of sericitized plagioclase and sericite - carbonate - chlorite clots after pyroxene, in a sheared, phyllitic matrix with disseminated opaques (TS 55770).

Dolerite

Hall (1967) reported "spilite" from the Mt. Read Road on the plateau, describing it as composed of albite laths and pyroxene in a chloritic matrix. The reported occurrence corresponds to the location where dolerites have since been mapped. Anderson (1972) describes lamprophyre dykes from the Pieman River gorge as sub-ophitic textured, with plagioclase in a chloritic matrix.

Numerous thin, cross-cutting dolerite dykes are present within the Mt. Black Volcanics on the Mt. Read plateau. In hand specimen they comprise small feldspar laths in a chloritic matrix.

Occasional dolerites occur in the Rosebery mine, and in one example a dyke with a beautifully chilled margin incorporating minor sulphides, wanders through D lens on an oblique traverse across the footwall, host rocks and hangingwall. This dyke may also be the one traced by a prominent magnetic signature on detailed ground magnetic profiles, from the hangingwall at the northern end of the orebody some 3km NNW, to Bobadil. Dolerite (presumeably the same one) is present on the continuation of that line, in the Pieman River gorge, having crossed the Rosebery Fault.

3.8 PERMIAN GLACIALS

A veneer of Permian tillite and glaciogene sediments is present in a few localities on the Mt. Read - Mt. Hamilton plateau. Sandstone, quartzite, volcanic and Owen Conglomerate cobbles are set in a claystone matrix. Crinoid stems have been reported and indicate a Permian age (M. Banks, pers. comm.).

3.9 QUATERNARY- RECENT GLACIALS

Quaternary to Recent glacial till and moraine occur extensively in all areas except the Mt. Read- Mt. Hamilton plateau. Unconsolidated boulder clay, with boulders to several metres diameter of various lithologies especially Owen Conglomerate, is typical. Fluvioglacials are found in the valleys of the Pieman and Stitt Rivers. A terminal moraine near Williamsford is concave to the south, indicating the glacier in the Pieman River valley was travelling south. Varved clay is common near the terminal moraine, but is also recorded elsewhere.

On the Bobadil plain, trenches in the glacial till penetrated into cobblestone, of rounded, well sorted cobbles with virtually no matrix, which are obviously fluvial deposits.

4 STRUCTURE

4.1 INTRODUCTION

Most previous authors, including Brathwaite (1969, 1972), Eastoe (1973) and Burton (1975a) recognised a major period of deformation and cleavage development which is correlated with the Tabberabberan Orogeny (Brathwaite, 1974).

Green (1983) recognised the Rosebery Fault in the Pieman River gorge, but assumed the fault continued to strike southwards and thus interpreted an anticlinal closure west of Rosebery to account for opposing dips. He also interpreted the structure of the "Rosebery Group" as a number of fault slices separated by tectonic slides, to explain the distribution of units and facings of the sequence.

Corbett and Lees (in press) describe a tectonically disrupted Dundas Group sequence which is interpreted as an accretionary complex developed on an east-dipping subduction zone.

One of the problems in the structural interpretation of the area is to "see through" Devonian (Tabberabberan) structures to differentiate earlier, Cambrian to Ordovician structures. Adams et al. (1985) report Ordovician ages for shales within the Stitt Quartzite (viz. 475±8, 480±8, 487±8 Ma) and Devonian ages (394±50, 397±23 Ma) for schists at the Rosebery mine.

The unconformity at the base of the White Spur Formation south of Hercules, is evidence of a significant structural event in the late Early to early Middle Cambrian (based on the age of Dundas Group in Adams et al. 1985). Cessation of major volcanic activity (the Mt. Black Volcanics at the top of the "Central Sequence") was followed by tilting and erosion of the "Central Sequence" prior to the subsidence or transgression which initiated deposition of the epiclastic White Spur Formation.

The structure of the area is dominated by the Rosebery Fault, which separates the Central Sequence volcanics from the Dundas Group on the western side of the fault with a different style of deformation dominated by a complex, anastomosing fault system. The fault is a major thrust with a down-dip displacement of at least 1.5 km, and near Rosebery contains a quartz-tourmaline vein.

Folds in the wedge of White Spur Formation east of the Rosebery Fault are moderate to open, with well developed steeply - dipping axial plane cleavage striking nearly due north.

Cleavage within the volcanics dips moderately to steeply east. Thin sedimentary lenses within the volcanics appear to have preferentially absorbed strain and are strongly cleaved and deformed. The ore lenses at Rosebery and Hercules show strong evidence of transposition.

4.2 CLEAVAGE S_1

Variably weak to strong cleavage is developed in the Mt. Read Volcanics and adjacent trough sequences. In the mapped area, variation in the intensity of cleavage is largely due to the pre-cleavage lithology; those most susceptible to the development of phyllosilicates become strongly cleaved quartz- sericite $\pm$ carbonate $\pm$ chlorite schists, while the majority of rocks, the felsic tuffs and lavas, show a weak cleavage and others, usually siliceous tuffs or massive lavas, remain virtually unaffected.

Cleavage development can be traced from relatively unaltered, weakly cleaved volcanics into zones of hydrothermal alteration related to ore deposits, where cleavage is quite strong. Chemical and mineralogical changes that accompany the development of cleavage, are due largely to the above relationship. Outside the alteration zones, the stable assemblage in felsic volcanics is quartz-albite-sericite. K-feldspar, noted as a secondary rimming on albite, appears to form a vague halo in quartz-phyric tuffs in the hangingwall, but plagioclase in the footwall is converted to sericite+carbonate, and becomes smeared, as alteration increases. The groundmass becomes schistose quartz + sericite $\pm$ chlorite $\pm$ carbonates. Axial plane cleavage accompanies the development of F1 folds. These are rarely seen in tuffs and lavas, but are seen within sediments and epiclastic tuffs of the Dundas Group, as open to tight folds on north to north - west trends. The only distinctions between cleavage on opposite sides of the Rosebery Fault are a subtle change in its attitude, as shown on the contoured plots of cleavage, although close to the fault the difference may be quite marked. The presence of tectonic melange zones is confined to the disrupted Dundas Group.

4.3 CLEAVAGE S_2

A weak second cleavage (S2) is present in the disrupted Dundas Group west of the Rosebery Fault, and as a weak cleavage or joint system east of the fault.

In the Hercules area, a prominent flat-dipping joint system occasionally shows evidence of kinking the first cleavage, and often is filled with quartz veins, similar to the quartz vein system associated with the Rosebery Fault west of Rosebery.

4.4 ROSEBERY FAULT

The position and nature of the Rosebery Fault, and therefore the relationships between Central Sequence volcanics and the disrupted Dundas Group rocks to the west, has been established, initially through detailed mapping and limited drill core data, and has been confirmed by subsequent drilling.

Green(1983) described the Rosebery Fault in the Pieman River gorge, but did not recognise it as a quartz - tourmaline vein further south, and assumed it to continue southwards through the Black P. A. prospect.

The Rosebery Fault can be traced south from the Pieman River gorge, through intersections in drillholes BD 1 and BD 269 at Bobadil, outcrops west of Rosebery and in the Stitt River, drillholes BP 97 and BP 99 in the Barkers area, the quartz-tourmaline vein at Salisbury and Chamberlain and drillhole CP281 beneath the latter, and exposures on the Williamsford Road and the Department of Mines recent Jupiter drillhole. The fault is covered by glacials in the Williamsford area, but reappears and can be traced to Moores Pimple, where it has recently been intersected in the Department of Mines Moores Pimple drillhole. From the White Spur Creek south of Moores Pimple the fault swings to the west, partly as a response to topography, and heads towards Mt. Dundas in dense rainforest.

Several drillholes in the Rosebery area have intersected the fault at significant depths, confirming its attitude and nature. R 1121, drilled from 8 level through the footwall sequence, and more recently 85R was extended to the fault after intersecting the Rosebery host rocks below the current limits of F lens. These intersections show the fault dips consistently east at 35° to 40° over its entire length, and that the down-dip component of its displacement is at least 1.5km (Plan 6), as no Central Sequence volcanics are so far known on the western and lower side of the fault.

Over much of its length, the Rosebery Fault consists of a puggy gouge or breccia, however between Rosebery and Jupiter a quartz-tourmaline vein-breccia is present.

In the Pieman River to Bobadil area, the fault consists of a thin, puggy clay within a one metre wide strong fault breccia, then several metres of strongly deformed, rolled sandstone lenticles in a sheared, slaty matrix, and eventually into typical Stitt Quartzite. On the Williamsford Road and in the Department of Mines' Jupiter drillhole, the fault is again of a clay pug in a strong breccia, but here is followed (to the west) by sheared, weakly brecciated and sericitized, silicified quartz-phyric tuffs of the White Spur Formation. The volcanics east of the fault are little altered, with only a few quartz veins (showing multiple deposition cycles) and a flat-dipping kink-cleavage system.

In the Department of Mines Moores Pimple drillhole, sediments of the White Spur Formation are truncated by a one-metre fault breccia of siliceous fragments in a sheared, slaty matrix. Quartz-porphyry, initially brecciated and altered for a few metres, follows.
Between Rosebery and Jupiter, the infilling vein-breccia varies between white quartz with a fine network of blue-green tourmaline, and a mass of radiating tourmaline crystals with cavities filled with drusy quartz crystals, and is surrounded by a zone of silicification, quartz veins and occasional tourmaline veins for a few metres into the hangingwall of the vein, and tens of

Fig. 34 . Strike- slip micro-faulting in dolomite of Westcott Argillite, Ring River, (5367890N, 374990E).

metres into the footwall.

4.5 STRUCTURAL DOMAINS

The area divides itself into three structural domains; these are:

i) West of the Rosebery Fault,

ii) White Spur Formation east of the Rosebery Fault, and

iii) Central Sequence volcanics east of the Rosebery Fault.

4.5.1 West of the Rosebery Fault

Green (1983) proposed a number of faults or "tectonic slides" to explain structures, relationships and facings of various units within the "Rosebery Group". Detailed mapping of the Rosebery Fault and adjacent areas has shown a significant difference in deformational style across the fault.

West of the Rosebery Fault, the Dundas Group is disrupted by an anastomosing fault system which divides the sequence into a number of fault slices or packets, each with its own stratigraphy. These vary from one to several kilometres in length and from a hundred metres to more than a kilometre in width. Descriptions of the faults or slides are contained in Green (1983), and are characterised by a change in bedding and sometimes cleavage across the fault, quartz veining near the lithological contact, and tightly folded rocks with pseudo-lenticular bedding close to the fault.

In addition to the tectonic slides, some units, especially the Stitt Quartzite, are susceptible to, and show, well-developed tectonic melange. This consists of blocks, phacoids, and boudinaged lenses of quartzite in a contorted slatey matrix. Good examples are seen in the Pieman River gorge (in the now-defunct "Munro Creek Slate" equivalent of the Stitt Quartzite) (Fig. 28) and at the Williamsford rugby ground (Fig. 29). It is likely that the melange is developed only close to major faults or near junctions of branches of the anastomosing fault system. Dolomites of the Westcott Argillite have behaved somewhat differently under similar conditions, and an example of deformation style within the Westcott Argillite is shown in Figure 34, from a location close to a junction of branching faults. Strain appears to have been absorbed by strike-slip movement along shale bedding planes within the dolomite, and possibly also by recrystallization of the carbonate.

In argillaceous sequences, deformation style near the faults is as that described by Green (1983). Chaotic folding is apparent as the slide zone is approached, and is marked by a breccia in places and a change in cleavage across the fault.

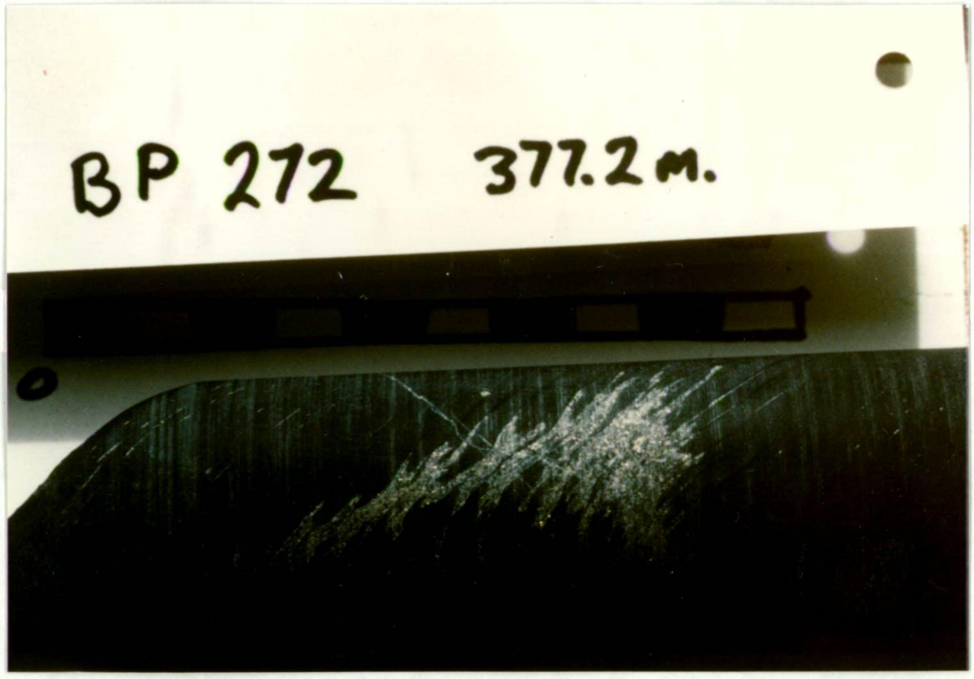


Fig. 35. Folded, partly transposed bed in shale, drillhole BP 272 377.2m.

Within each fault-bound slice or packet, lithological units maintain consistent stratigraphy and structure. Cleavage is uniformly steeply dipping. Folds are rarely seen on either outcrop scale or megascopically due to the intense fault disruption. Exceptions are the synclinal closure in the Pieman River gorge (see below), and folds interpreted from drillcore data, mainly facings and vergence, in the window of White Spur Formation west of Rosebery. Folding asociated with cleavage development in this area is intense enough to cause transposition, as shown in Figure 35.

A major synclinal structure, described by Green (1983), is found in the Pieman River gorge at 5377800N, 376800E. Mapping of this area shows a distribution of marker conglomerates and facings, indicates a tightly compressed synform, actually composed of two tight synclines separated by an anticline (Fig. 36).

A stereographic plot of 70 cleavage measurements west of the Rosebery Fault give an optimum cleavage orientation of 00/90° (Fig. 37), which is only slightly different to the mean cleavage orientations east of the fault. Green (1983) measured cleavage and bedding in the Pieman River gorge section, and found that cleavage had a maximum near 345/90°, with fold plunges forming a girdle around this orientation.

4.5.2 <u>White Spur Formation East of the Rosebery Fault</u>

The White Spur Formation east of the Rosebery Fault and south of Williamsford is moderately to tightly folded, but shows a different style and degree of deformation than the disrupted Dundas Group west of the fault. The wedge - shaped distribution of the formation is controlled by the Rosebery Fault to the west and the unconformity to the east. From the northern apex of the wedge, a major south - plunging syncline, initially overturned, can be traced southwards. As the wedge widens, a number of parasitic folds of smaller amplitude appear, and eventually a series of open, shallowly plunging folds are present across the southern boundary of mapping.

Axial plane cleavage associated with the folds dips steeply to the east, with a maximum at 358/82°E. A slight change in the orientation of cleavage relative to the adjacent volcanics (max. at 346/80E) is noted, and may be due to a combination of the cleavage vergence across the folds, and refraction of cleavage in sediments being different to that in volcanics. Cleavage in the Dundas Group west of the fault has a similar average orientation, but somewhat different spread of values (Fig. 37).

A series of folds, shown on K. Corbett's (1984) mapping south of the area, are present in White Spur Formation but are poorly defined in the underlying volcanics.

On Howards Road, Adams et al. (1985) report K-Ar ages of 455$\pm$ Ma (Ordovician) and 298$\pm$4 Ma (Carboniferous) for slates in the White Spur Formation. The Ordovician age may

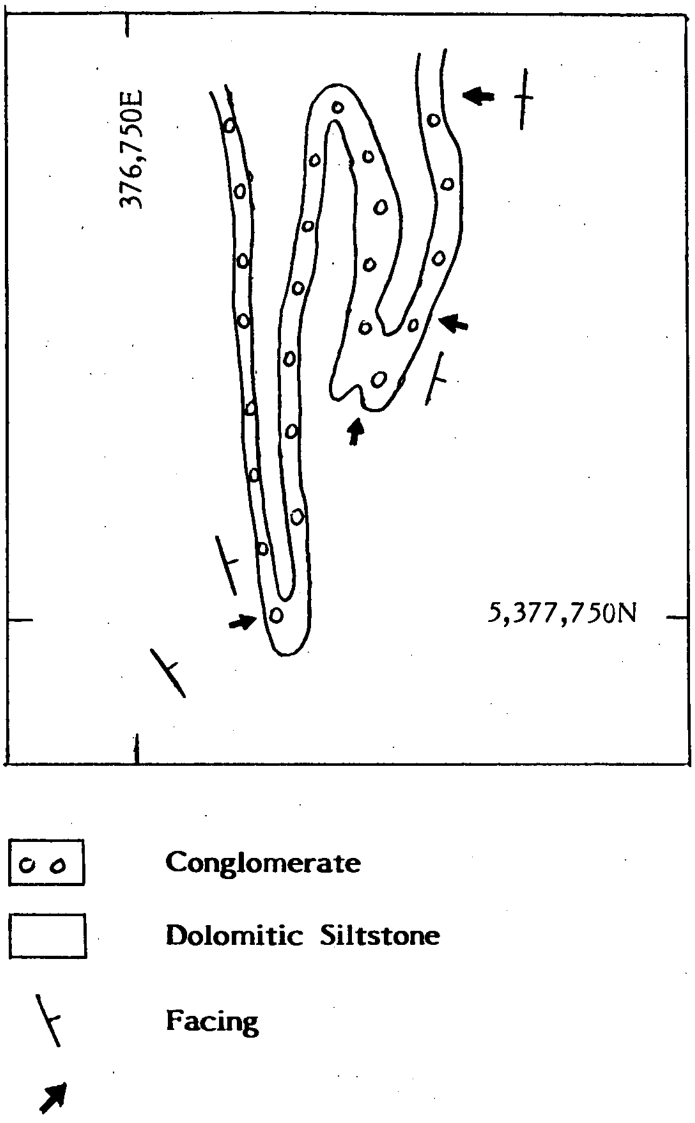


FIGURE 36 - <u>Interpreted plan view of fold in conglomerate, Pieman River Gorge.</u>
(Scale 1:2,500)

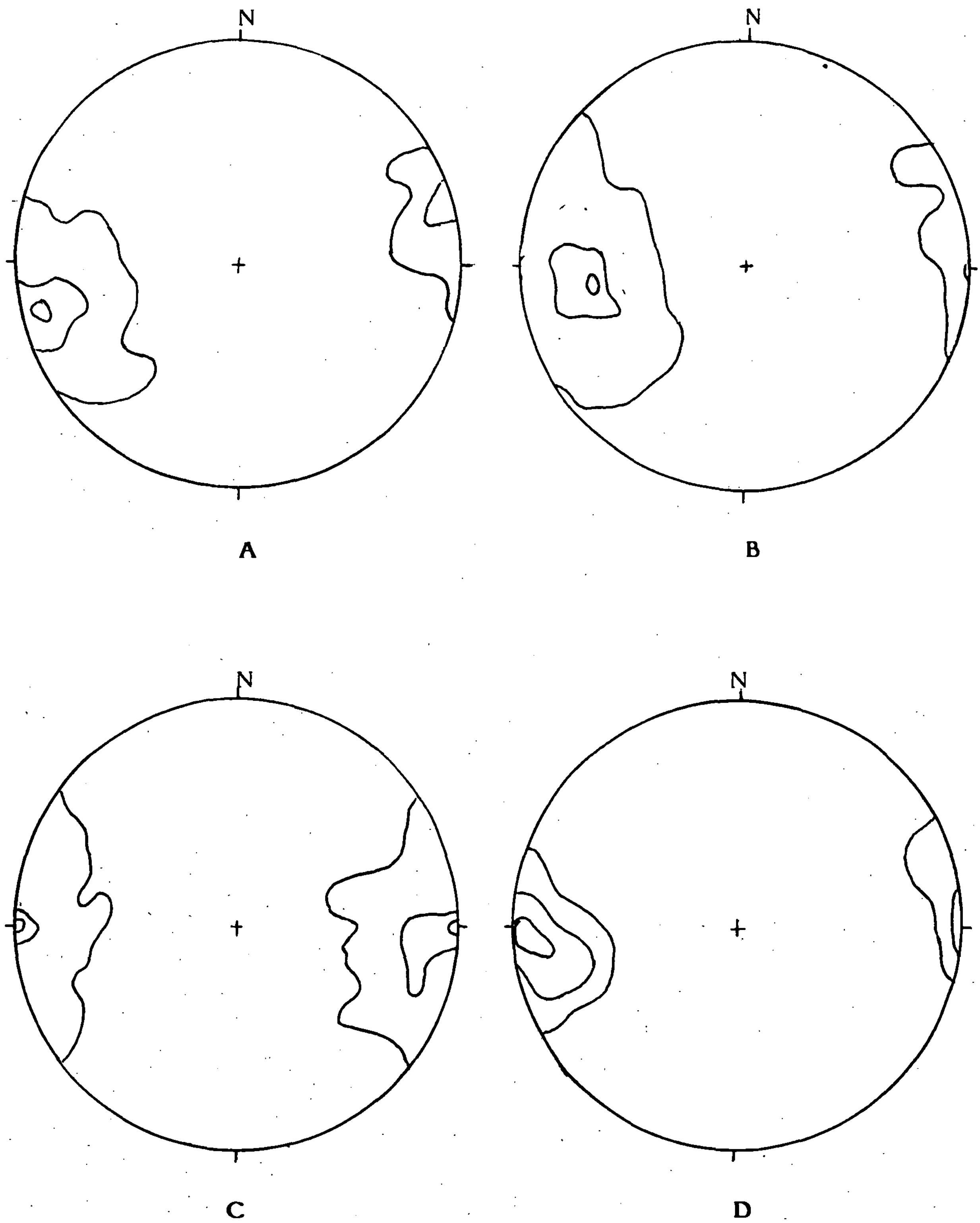


FIG. 37 - Contoured stereographic plots, of 1%, 10% and 20% per 1% area, for A) Mt. Read Volcanics (North); B) Mt. Read Volcanics (South); C) Dundas Group E of Rosebery Fault; D) Dundas Group West of Rosebery Fault

reflect the early age of deformation of the Dundas Group, or may be a partial re - set of an original age, and the significance of the Carboniferous age is not known (Adams et al., 1985).

4.5.3 East of the Rosebery Fault

The structural style east of the Rosebery Fault is relatively simple. Cleavage dips consistently moderately to steeply east on N-NNW trends, depending on vergence of major folds, and faulting is relatively unimportant.

Faults

Faulting is relatively minor, and quite different in style to those west of the fault. At Hercules, the host rocks are disrupted by a NW trending set with right-lateral displacement, which is in the order of only a few metres in all cases. Bakers Creek Fault is the most prominent, having a one-metre fault breccia averaging 121/50°N, while a small pug zone marks Fellows Fault oriented at 108/30°N. Bakers Creek Fault splits into two divergent faullts near JK lode, producing a splayed branch, the Intermediate Fault oriented at 154/45°E, and with a right lateral displacement of 15m. The Mt. Hamilton Fault is a strong shear zone at the northern end of the Hercules deposit; in fact the host rocks and shales terminate against it. Interpretation of geology from mine plans indicate a strike of 137° and a steep northerly dip.

One of the few other faults recognised is some two kilometres SE of Rosebery, and is again on a NW strike with a right - lateral displacement of about 100m of a basalt.

A quartz - tourmaline filled vein which extends from Rosebery SSW to Bald Hill is parallel to the Rosebery Fault, and may be a small fault or fracture related to it.

Folds

Folds are rarely observed in massive tuffs or lavas, and are best seen in sedimentary horizons within the volcanics.

Facings and vergence at Rosebery indicate that it is on the east limb of an overturned antiform, but the closure is not present as it has presumeably been thrust underneath the Rosebery township by the Rosebery Fault.

Hercules is also on the east limb of an anticline, but lies relatively close to the closure, as shown in Fig. 38. Flat dips on nearly symmetrical, open folds at West Hercules may indicate the position of the anticlinal closure, which is tentatively called the Copper Ridge Anticline. Indirect evidence for the anticlinal closure is in the vergence across the footwall pyroclastics in the belt between Hercules- North Hercules and the Rosebery Fault - White Spur Formation. Cleavage gradually steepens from about 70° east through vertical to steeply west in the westernmost outcrops. The trace of the anticline, trending just west of north from West Hercules, would intersect the Rosebery Fault near Williamsford.

South of Hercules, the anticline is difficult to locate because of the added complication of the unconformity at the base of the White Spur Formation. Shallow to steep west dips in the basal White Spur Formation are a function of both structure, determined by the folding, and the degree of unconformity at its base - which must be considerable to account for the abrupt steepening of dips across the unconformity, and the distribution of White Spur Formation around a poorly defined fold nose at South Hercules and its absence east of the Copper Ridge Anticline. In Bakers Creek, steep westerly dips of flattened pumice fragments below the unconformity become flatter and eventually east- dipping across the fold axis.

Consistent moderate southerly dips in feldspar - phyric tuffs at South Hercules are evidence that a fold closure is present in this area. A syncline - anticline pair, well defined in White Spur Formation mapped by K. Corbett further south, probably correspond to poorly defined folds in the "central sequence" volcanics. These folds are the cause of a large embayment of White Spur Formation, having E-W strikes and shallow south dips, near 5364000N. The protruding ridge of feldspar-phyric tuffs within the low-amplitude anticlinal fold of White Spur Formation, marks the position of the Copper Ridge Antiform.

Cleavage

Cleavage in the volcanics east of the fault was plotted for two areas, separated by an arbitrary E-W line at 5367000N. Contoured plots of stereographic projections for this data are shown in Figure 37, each data set comprising 150 points.

In the northern part of the volcanics, cleavage plots at a maximum of 350/60°E, which closely corresponds to Brathwaite's (1969) maximum of 350/58°E. Bedding in the Rosebery mine plots at 340/53°E (Brathwaite, 1969), from which it can be concluded that the Rosebery ore deposit is on the east limb of an overturned anticline. In the southern part of the area, cleavage plots at a maximum of 346/80°E, a slight change in orientation that may be due to the effect of the Rosebery Fault on the northern area.

4.6 TRANSPOSITION

4.6.1 Transposition of Ore Lenses

It becomes fairly obvious, when looking at plans and sections of the Hercules mine area (see Sect. 6.3) that the ore lenses are transposed into the cleavage. The ore lenses are found within strongly cleaved and deformed zones, which appear to intrude host rocks, and are quite distinct from the relatively undeformed host rocks.

The Rosebery orebody has also undergone some degree of transposition, as illustrated in Fig. 38, which shows an *en echelon* distribution of small sulphide lenses, and prongs of ore related to folding. This pattern is also repeated in examples ranging from megascopic to the overall morphology and distribution of the ore lenses. Massive, recrystallized carbonate, commonly rhodochrosite, usually forms a pod at the end of each sulphide lens. It is suggested that carbonate from the (carbonate - rich) halo surrounding the orebody, was remobilised during folding and migrated to the low pressure areas, where it was re - deposited.

The apparent difference between deformation at Rosebery and Hercules, with Hercules showing obvious transposition, can be attributed to the position of the ore lenses with respect to major folds.

4.6.2 Deformation of Pumice

Folding and cleavage development have an effect on pumice fragments, which depends on:

- susceptibility of pumice to compaction and alteration
- pre-folding pumice shape, and
- position relative to fold axes.

Spheroidal pumice will be attenuated into the cleavage, while originally flattened pumice will be partly transposed into the cleavage, as shown in Fig. 39, while those close to the axial plane will approximate spheroids.

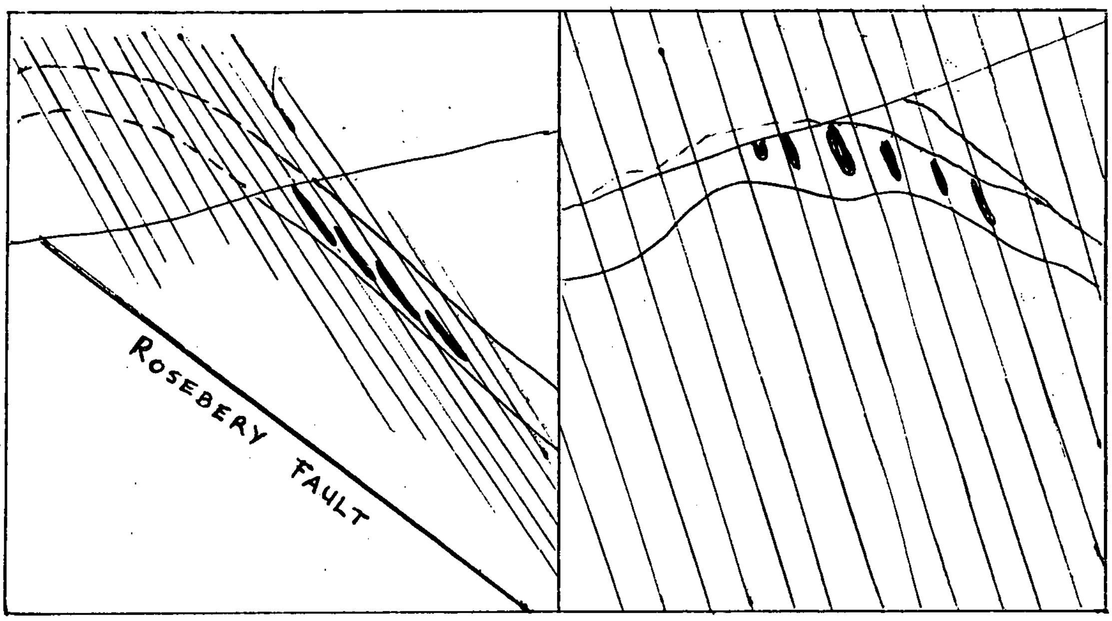


FIGURE 38 - Relationship between the Rosebery (L) and Hercules (R) ore deposits, and folds with axial plane cleavage.

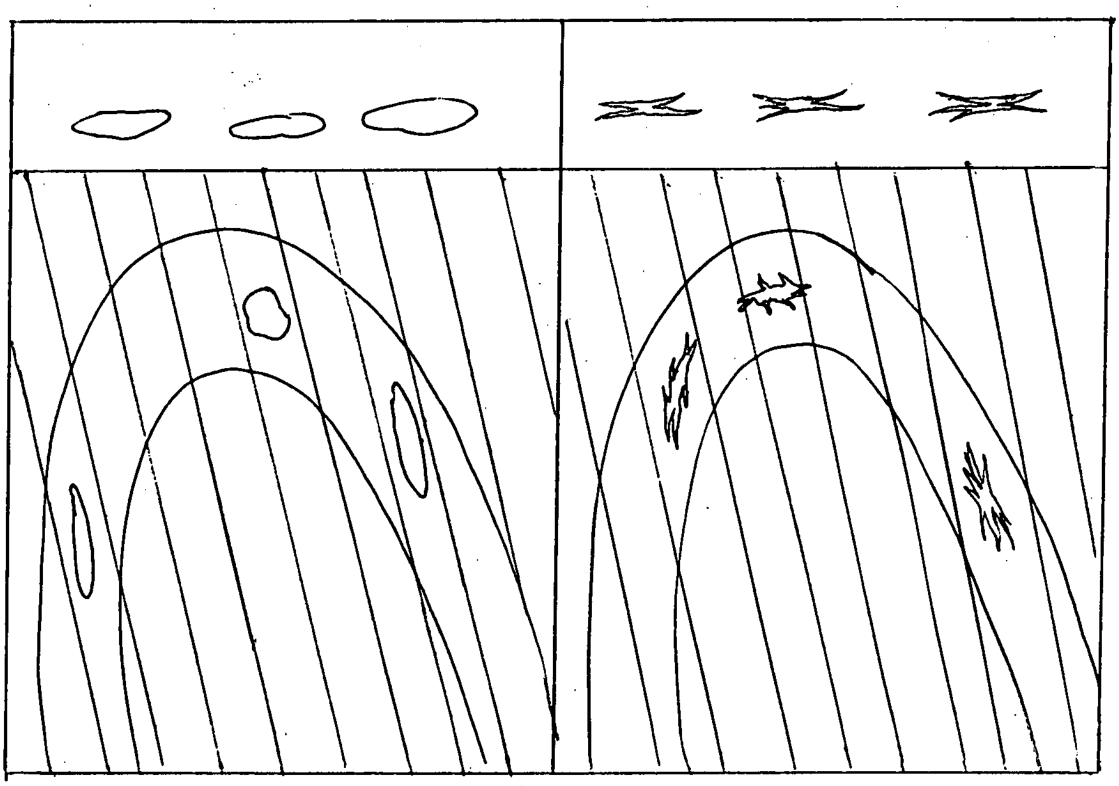


FIGURE 39 - Deformation of pumice relative to folding; of original pumice lithics (left) and fiammé (right)

5 INTERPRETATION OF STRATIGRAPHY

5.1 FOOTWALL PYROCLASTICS

The oldest rocks known in the area, the "footwall pyroclastics", show evidence in their distribution, lithological associations and textures, for deposition as ash flows which are in some cases welded. These are broadly of dacitic to rhyolitic composition, as indicated by the phenocryst mineralogy and general felsic character rather than by chemical analyses, as the true igneous parent magma composition is probably preserved most closely in pumice fragments. Several authors, including Ross and Smith (1961), Lambert (1974), and Peterson (1979), point to significant diagenetic alteration of pumice (see also Sect. 8), therefore pumice composition was not determined.

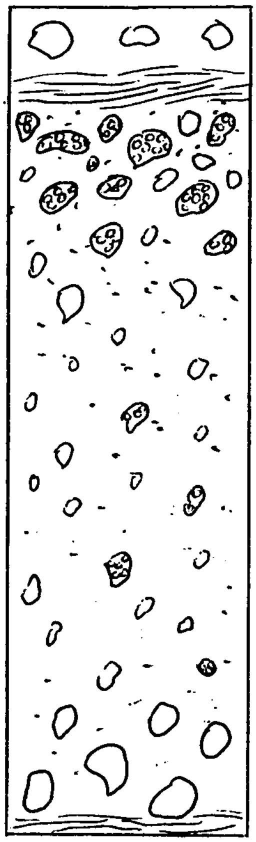
Analysis of the footwall pyroclastic sequence, in terms of internal features and relationships, indicates they can be compared to an idealized model of pyroclastic flow (Fig. 40), of Cas and Wright (1983). Features common to the Rosebery area and the idealized model are the unsorted, massive nature of the main part of the flow unit, with lithics concentrated at the base and pumice at the top, and thin ash layers between flow units. Obviously erosion and epiclastic processes acting during deposition of the sequence modify the idealized section. The "preservation potential" especially of unconsolidated ash tuffs and unwelded tops to pyroclastic flows is low, so that a compressed sequence, containing mainly more resistant, welded tuffs and the basal parts of ash flows, could be expected.

Welding textures are occasionally preserved in the footwall pyroclastics, but at least part of the sequence was deposited subaqueously. The thin massive sulphide deposits at the Ring P. A. and Jupiter prospects, and minor sediments and epiclastics in a few localities, attest to this. On the whole, however, the lack of sediments associated with the sequence would indicate a largely subaerial environment.

A major, district wide event is recorded at the top of the feldspar - phyric footwall pyroclastics. The event is reflected in four coinciding circumstances, namely, a change in style of the deposited sequence, a change in composition of rocks, from feldspar-phyric to quartz + feldspar-phyric, ore deposition at Rosebery and Hercules at this point (although mapping is not conclusive as the parallel sequences are regarded as sufficient evidence for this argument, and deposition of a widespread sedimentary horizon commenced at this point in time, and persisted for a considerable time and distance.

It can be concluded that rapid subsidence was the cause behind these related events, as all the changes brought about reflect a change from a subaerial and shallow water, to a moderately deep marine environment.

A requirement necesary for the formation of a massive sulphide deposit is that there is a



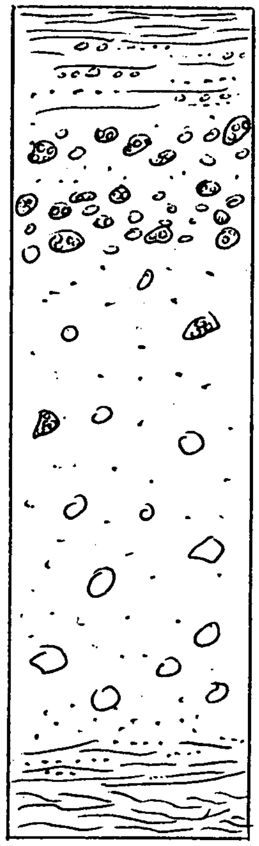


FIG. 40 - **Features of footwall pyroclastics in the Rosebery area (above) and idealised model of pyroclastic flow (below)**
(From Cas and Wright, 1983)

sufficient depth of water required to prevent substantial boiling of a hydrothermal solution reaching the seafloor (Ridge, 1974). Depth estimates to prevent boiling for a solution at 275°C is 500 metres (Haas, 1971), or at 250°C is 400 metres (Plimer, 1981).

The reason for rapid subsidence in volcanic terrains is often attributed to caldera subsidence (Smith and Bailey, 1968; Lipman, 1975; 1984). In the subaerial examples studied, collapse is not usually related to ore-forming processes, which in this setting accompany much later hydrothermal activity (e.g. Lipman, 1984).

Green (1983, p. 9.1) proposes a cauldron collapse mechanism at the end of the footwall pyroclastics to explain the lithological changes and subsidence, which is in agreement with the evidence outlined above.

It seems likely, then, that the footwall pyroclastics are ash flows, corresponding to the caldera- forming eruptions (Stage 2) of Smith and Bailey (1968), and were followed by collapse of the caldera which caused rapid subsidence, a change in the nature of volcanic products (although they may have been derived from the same but now slightly more fractionated source), and initiated the ore-forming process. Fig. 41 shows the possible progressive development of Mt. Read Volcanics during caldera formation, subsidence, resurgence during deposition of the hangingwall epiclastics, and later Mt. Black Volcanics and White Spur Formation.

5.2 QUARTZ - PHYRIC EPICLASTICS

Characteristics of the quartz - phyric epiclastic sequences are shown in Fig. 19. Common features are the basal lithic-rich breccias, which grade up to massive crystal tuff with sparse lithics, then reworked tuff and sediments at the top of the flow unit. The logical interpretation of this consistent lithofacies is that it was deposited subaqueously as a series of mass flows which interrupted a quiet sedimentary regime.

In the Rosebery mine area, quartz - phyric tuffs overlie black slates, but as mentioned above, the change from feldspar, to quartz plus feldspar - phyric volcanism occurs within the host rocks.

Shale - hosted, open framework breccias of contorted felsic lithics in a disturbed shale matrix are present at several localities. These are interpreted as subaqueous debris flows, initiated by felsic volcanic material slumping into a quiet sedimentary environment.

In the Hercules area, the quartz - phyric tuffs are interspersed with feldspar - phyric tuffs similar to those of the footwall pyroclastics. These probably represent thick ash flows deposited subaqueously, as a further sedimentary - epiclastic regime was established in the Dallwitz- Jones Creek sequence.

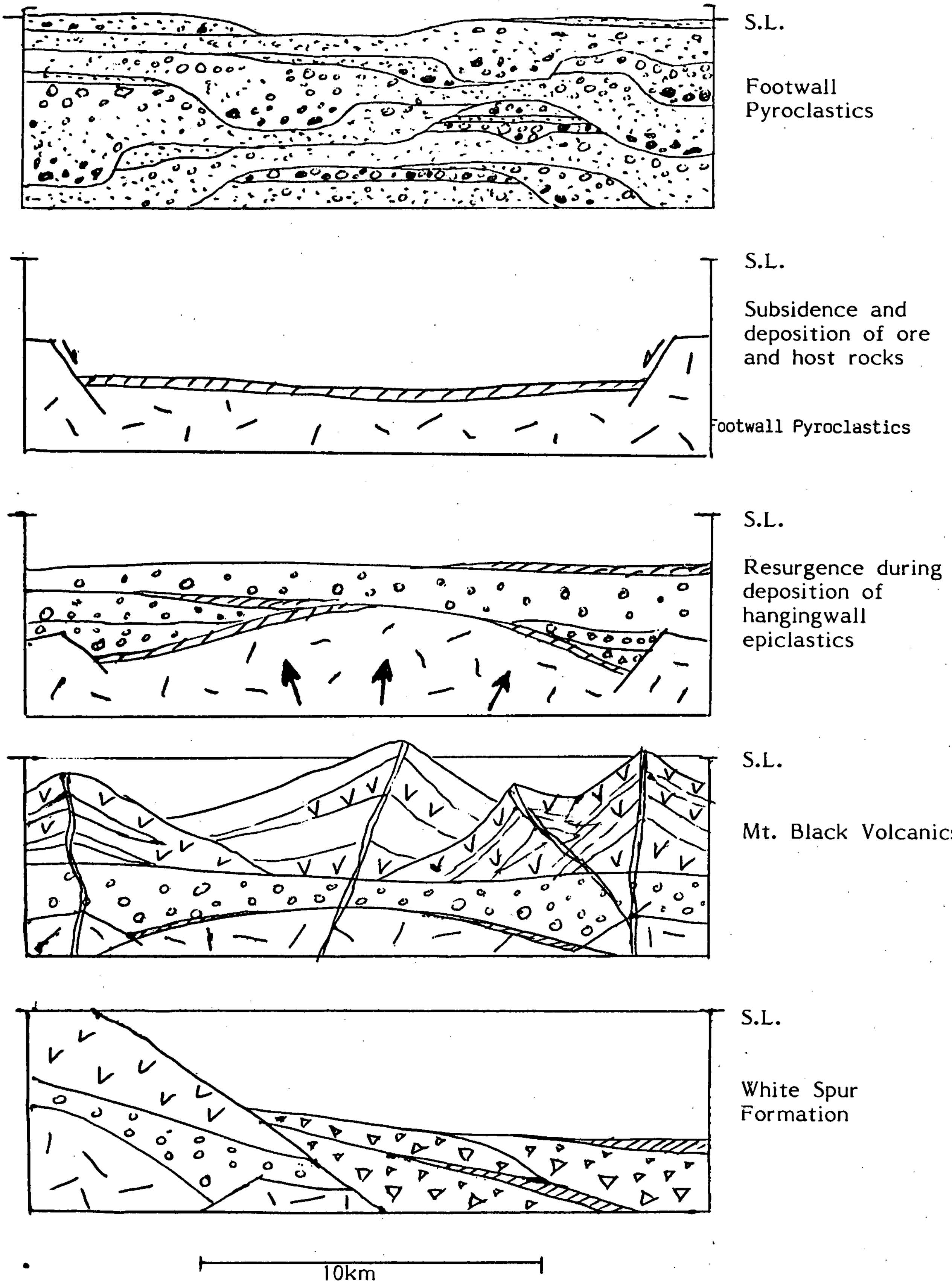


FIGURE 41 - Progressive development of Mt. Read Volcanics and White Spur Formation in the Rosebery area.

Bedded pelitic ash containing lithophysae at South Hercules is closely asociated with, and immediately overlying, a coarsely pumiceous ash flow, which is probably an ignimbrite. The close association suggests a possible genetic relationship to the ignimbrite, which would then point to the pelitic ash having been deposited as an ash cloud surge, similar to those described by Fisher and Schmincke (1984). Bed forms present at South Hercules are consistent with those described for ash cloud surge deposits, but may also be formed by normal sedimentary processes so that a volcanogenic sedimentary origin for the pelitic ash cannot be ruled out. No antidune bedding structures, which typify base surge deposits (Cas and Wright, 1983), were observed.

5.3 MT. BLACK VOLCANICS

Massive andesite to dacite lavas, with minor tuffs, epiclastics, sediments and limestone, overlie the quartz-phyric tuffs with apparent conformity, although in many drilholes the contact is strongly faulted.

North of Rosebery, an andesite-basalt sequence is silicified around its southern margin. Extensive brecciation and veining is apparent in some areas, with some indications that these are hydrothermal breccias. Vesicular zones, and minor intercalated tuffs and sediments, indicate several flows were emplaced, probably subaqueously.

At the base of the thick, massive dacite lavas are flow breccias and pumiceous lava-breccias, which probably include hyaloclastite types. Features of these lavas are similar to subaqueously erupted felsic and basaltic hyaloclastite lavas described by Furnes and Sturt (1976), de Rosen - Spence et al. (1980) and Furnes et al. (1980). In particular, the flow - breccias containing fragments, small lenses and pods of chilled lava in flow - oriented to flow - brecciated lava (Fig. 23) and pumice - bearing lava - breccias (Fig. 24), are features typical of hyaloclastites.

Following is a thick sequence of mainly massive dacitic lavas, which are variably flow - brecciated and flow - banded in places and with pumice - like flow - streaks. Minor hyaloclastite lava types within this massive sequence may represent the margins of voluminous flows, the cores of which remain unaffected by the explosive mode of emplacement into water. Minor sediments, including limestone, are further evidence that at least the basal part of the lavas were erupted subaqueously.

Basalt and andesite lavas occur higher in the sequence and extend east to the Henty Fault Zone, at least on the Murchison Highway section. In the Pieman River section, Anderson (1972) shows rhyolitic quartz - and quartz - feldspar - porphyries to be succeeded eastwards by dacitic feldspar porphyries that extend to the junction of Murchison and Mackintosh Rivers.

5.4 SYNTHESIS - MT. READ VOLCANICS

Correlation of various units within the Mt. Read Volcanics in the Rosebery - Hercules area is illustrated in Fig. 42, while progressive development of the area, in terms of the interpreted origin of these units is shown in Fig. 41. Deposition of extensive ash flow tuffs of the footwall pyroclastics was terminated by rapid subsidence, accompanied by ore formation in a quiet sedimentary regime. The succeeding hangingwall epiclastics are believed to be subaqueously deposited mass flows, and minor sedimentary units are intercalated. The Mt. Black Volcanics represent a new phase of voluminous dacite to andesite lavas with minor tuffs.

5.5 WHITE SPUR FORMATION

The White Spur Formation overlies the Central Sequence volcanics unconformably. The degree of unconformity is shown to be considerable, indicating erosion took place to create a landscaped surface with substantial relief, prior to deposition of White Spur Formation.

The White Spur Formation is tuff - rich at the base; in general the proportion of interbedded shale and siltstone increases towards the top of the unit. The thick tuffs at the base have a number of features, similar to those of the quartz-phyric tuffs, that indicate they were deposited subaqueously as mass flows. These features include basal lithic-rich breccias, the lithics decreasing in size and abundance upward into the bulk of the unit, consisting of lithic-crystal tuff with occasional lithics and abundant feldspar and minor quartz crystals. The top of each unit is marked by reworked, matrix - depleted tuffs, which pass into interbedded volcanogenic sandstones, siltstones and shales. Crystal-rich tuffs within sediment-dominated sections are probably distal equivalents of mass flows.

The Chamberlain Shale member at the top of the formation represents a period of quiet sedimentation in a open marine environment, and the end of epiclastic activity.

5.6 STITT QUARTZITE

Comformably overlying the White Spur Formation is approximately 300m. of quartz - arenite and thinly interbedded shale, which is interpreted to have been deposited largely by turbidites, but some well-sorted, massive sandstone beds may represent local shallow conditions in an offshore bar or barrier beach deposit. The majority of the unit probably represents a prograding delta, with the laminated shale - siltstone - sandstone facies having been deposited in the distal part of the submarine fan, a conclusion already reached by Green (1983).

The dominance of quartz and muscovite as constituents of the Stitt Quartzite indicate its

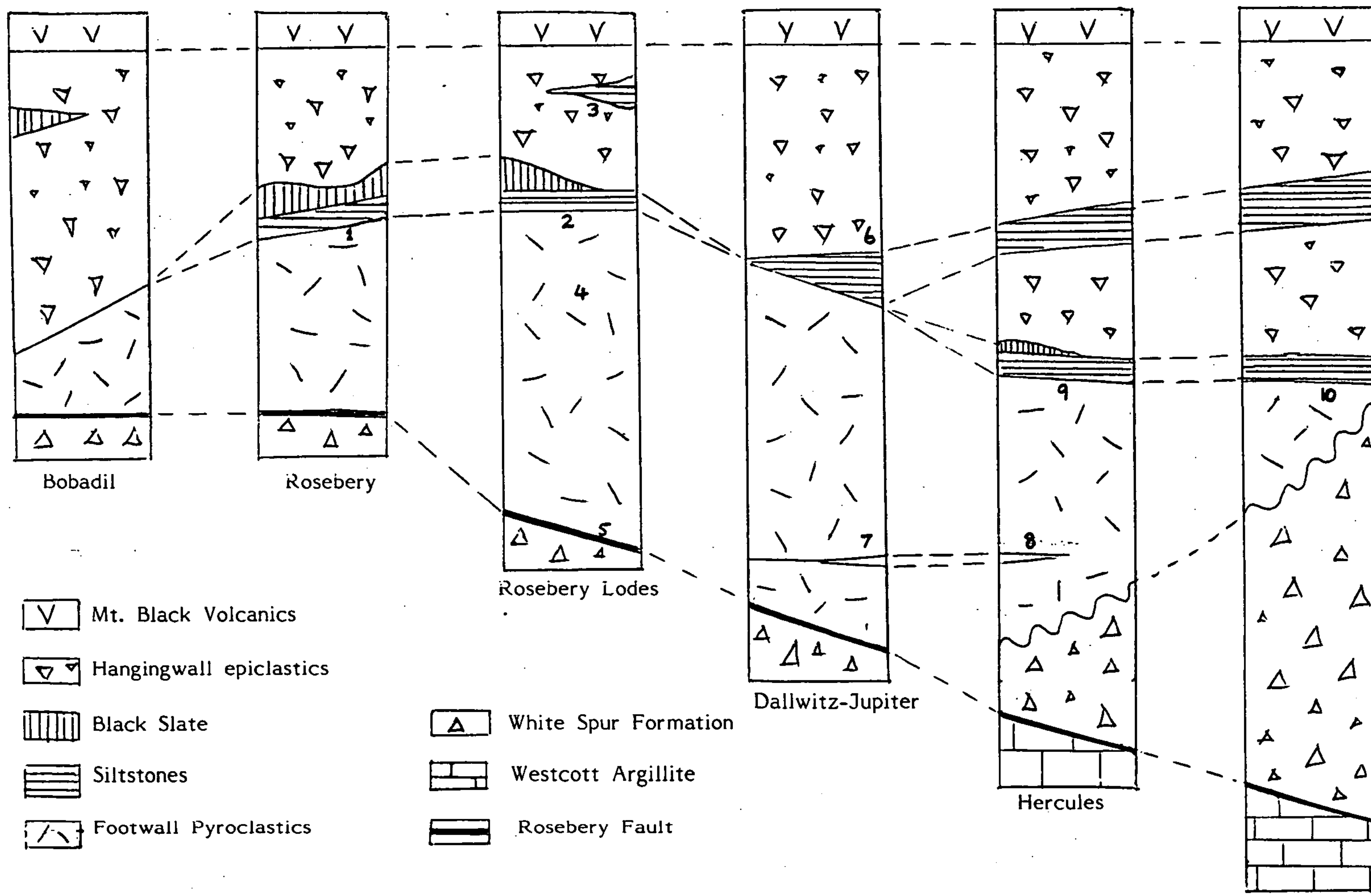


FIGURE 42 - Correlation of Mt. Read Volcanics in the Rosebery-Hercules Area: (plan view) Mines and Prospects numbered as follows:-

1. Rosebery 2. Rosebery Lodes 3. Dalmeny 4. Koonya
5. Chamberlain, Salisbury 6. Dallwitz 7. Jupiter 8. Ring P.A.
9. Hercules 10. South Hercules

Note: These are not stratigraphic columns, but an overall plan representation.

provenance is in the Precambrian quartzites, but rare volcanic grains are probably locally derived.

5.7 WESTCOTT ARGILLITE

At least 350 metres of dolomite, dolomitic siltstone and dolomitic wacke of the Westcott Argillite is commonly in fault contact with the Stitt Quartzite, but a conformable, gradational contact is present in the Pieman River gorge.

Green (1983) regarded the Westcott Argillite as a distal turbidite facies. Abundant carbonate (now largely dolomite) in the unit must be taken into account when considering the environment of deposition.

Modern carbonate-rich sediments are usually found distant from clastic sources, in such places as oceanic islands, offshore banks and peninsulas (Cook and Mullins, 1983). Characteristics of the basin-margin environment (Cook and Mullins, 1983) are the presence of conglomerate and mega-breccia of mass flow origin, within a sequence of extensive fine-grained pelagic and hemi - pelagic sediments, mainly lime mudstones, calcilutites and wackestones. From this it is clear that factors responsible for deposition of the Stitt Quartzite have changed markedly; either the source is no longer contributing, or the assumed river system is no longer active in the area. The presence of intraformational conglomerate near the top of the unit would suggest a deep marine environment for the Westcott Argillite, but fairly close to the basin margin.

Green (1983) notes the presence of clasts of length - slow spherulitic chert, which he provides evidence for as forming as a replacement product of evaporite minerals, attributing their source to the Smithton Dolomite, or a pre-existing Cambrian dolomite.

The source of probable evaporitic detritus in mass flow conglomerates, obviously derived from up the depositional slope, merely requires evaporites to have been present within the sequence at the source area. A change in provenance may be all that is required to produce a change from Stitt Quartzite to Westcott Argillite; for example from an active river system discharging into a submarine fan, to a sabhka or tidal flat environment with no active river system.

5.8 SALISBURY CONGLOMERATE

The Salisbury Conglomerate, a closed framework conglomerate of various rounded clasts in a dolomitic or sandy matrix is interpreted as a distributary channel facies of a submarine fan.

Several reaons for this are given as follows:

- Rounding of clasts indicates active transport,
- Variety of clast lithologies indicates large source area,
- Closed framework indicates gradual deposition, in comparison to the open framework mass flow conglomerate,
- Multiple fining-upwards cycles within the conglomerate were intersected in the Department of Mines Natone drillhole (see Green, 1983), indicating depositional cycles,
- Interfingering with the Westcott Argillite suggests submarine conditions.

5.9 NATONE VOLCANICS

The Natone Volcanics are closely associated with the Salisbury Conglomerate, and are seen to interfinger at several localities. The crystal-lithic tuffs usually contain shale lithics, also in places pebble bands, and a number of separate flows can be distinguished.

These are interpreted as ash flows deposited in shallow marine conditions, within a distributory channel system.

At Moores Pimple, porphyritic rhyolite grades to rhyolite breccia with shale and shale-hosted breccia infilling crevices in the rhyolite. Chilled margins to the lava at sediment interfaces, and probable hyaloclastite types have been recognised. Mass flow breccias, of mainly rhyolite fragments in a shale matrix, are often adjacent. The implication of a quartz-porphyritic rhyolite lava at this stratigraphic level is that it is related to the Natone Volcanics.

5.10 SYNTHESIS - DUNDAS GROUP

Green (1983) compares the Stitt Quartzite, Westcott Argillite and Salisbury Conglomerate to facies triplets described by Rupke (1977), in which an ascending sequence of mudstone, sandstone and conglomerate represents progradation of a submarine fan and distributary channel, despite the "muddled" sequence at Rosebery. The progressive development of the Dundas Group is illustrated in Fig. 42.

Several features are evident when considering the Dundas Group in the Rosebery area as an entity. The first is the upward decreasing epiclastic component of the White Spur Formation. Quiet, open marine conditions were periodically interrupted by the influx of mass flows, which had all but ceased at the top of the formation in the Chamberlain Shale member.

Quartz - rich clastic detritus, deposited mainly as turbidites during building of a submarine fan, are represented by the Stitt Quartzite. A few massive sandstone beds may represent shallow conditions and the effect of wave action in an offshore bar, while a laminated shale-siltstone facies was deposited in the distal part of the fan.

The Westcott Argillite was deposited in quiet marine conditions, with some input from steep basin margin slopes of mass or debris flow conglomerate.

The Salisbury Conglomerate was deposited in a high energy, probably shallow water environment, and are the channel lag deposits of an active river system. Ash flow tuffs of the Natone Volcanics are admixed with the Salisbury Conglomerate and presumeably flowed down the river valley from their source. A rhyolite lava showing good evidence for having been emplaced subaqueously, is present at Moores Pimple, but is not associated with typical Salisbury Conglomerate.

Ash flow tuffs, produced by explosive volcanism, and rhyolitic lava within the Dundas Group, at a considerable time after volcanism in the main part of the Rosebery arc ceased, shows that volcanic activity resumed, at least briefly, and was perhaps coeval with deposition of the Tyndall Group arc volcanics, which K. Corbett (pers. comm.) regards as probably equivalents to the Dundas Group.

6 MINERALIZATION

6.1 INTRODUCTION

The main aim of this section is to describe the various occurrences and styles of mineralization, and present new data, observations and interpretations where relevant.

As so much of the literature is concentrated on Rosebery, a brief summary of some of this work is presented along with new work. The Hercules deposit, although a fraction the size of Rosebery, is discussed in as much detail as it has been poorly documented in the past. Precious metal mineralisation closely associated with base metal mineralization at South Hercules is described briefly.

Rosebery Lodes has a stratigraphic sequence similar to Rosebery but only minor mineralization apparently of a similar style. Small occurrences of base-metal mineralization in the stratiform Pb-Zn-barite lodes at Ring P.A. and Jupiter, and stringer-type mineralization at Dalmeny and Koonya, are discussed.

A completely different style of mineralization is intimately associated with quartz tourmaline veins, especially along the Rosebery Fault, and contains minor sulphides with minor Au and a range of other elements. Quartz-galena veins in Dundas Group rocks are briefly compared to the other styles of mineralization.

6.2 ROSEBERY

6.2.1 Introduction

The discovery of Rosebery is attributed to Tom McDonald, who in 1893 traced boulders of massive sulphide in Rosebery Creek to their source.

From discovery until June 1986, approximately 13.6 m tonnes of ore have been mined at an average grade of 5.0 % Pb, 16.3 % Zn, 0.74 % Cu, 166 g/t Ag, 2.8 g/t Au and 16.5 % Fe. Reserves at that time were some 7.7 m tonnes averaging 5.0 % Pb, 15.7 % Zn, 0.65 % Cu, 122 g/t Ag, 2.8 g/t Au and 13.8 % Fe, giving a total known resource of some 21.3 m tonnes.

The Rosebery orebody has been studied in detail by numerous authors. The most significant contributions are of Brathwaite (1969) who established Rosebery as a volcanogenic massive sulphide deposit, and Green (1983) who described the formation of the orebody.

6.2.2 Stratigraphy

The stratigraphy of the Rosebery area has been described in Section 3, but a brief review of the sequences in the mine area follows.

Footwall pyroclastics

The "footwall pyroclastics" in the mine area are altered to quartz- sericite $\pm$ chlorite schists ("quartz schist") which are typically augen textured with siliceous augen defined by anastomosing sericite foliae. Chlorite schist and sericite- chlorite schist bands often occur underneath ore lenses.

In the barren gap between the northern and southern groups of lenses, the "footwall pyroclastics" are less altered, and consist of silicified feldspar and collapsed, sericitic pumice fragments, in a weakly silicified and sericitized felsic matrix.

Host rocks

The host rocks consist mainly of tuffaceous siltstones, now largely converted to sericitic schists. Towards the top of the host rock sequence, and above the position of the barite mineralization, sandstones and greywackes are quite common, often showing internal grading of grain size (fining upwards), with quartz and small, various lithic grains being the main discernable components in a fine-grained matrix.

Thickness of host rocks in the mine is from 5 to 150m, which is a function of original thickness, erosion largely due to the influx of quartz- phyric epiclastics, and folding. The original true thickness was in the order of 5 to 70m, with local substantial thickening due to folding.

A quartz- bearing volcanogenic wacke is present within the host rocks at the north end, immediately overlying the ore position at the footwall pyroclastic / host rock contact, but underlying weak baritic mineralization. Structure contours of this unit show it to thicken northwards and with depth, causing an effective increase in host rock thickness, although without this unit the host rocks are quite thin.

Black slates

The black slate occurs above the host rocks over much of the northern part of the deposit, and sporadically over the southern part. Stratigraphic thickness is up to 40 metres, which may be considerably increased by folding. Finely bedded slate of sericite, chlorite and quartz is locally graphitic, and contains minor pyrite or pyrrhotite and abundant thin quartz- carbonate veins. Thin sandstone and lithic wacke beds are commonly a minor component.

Quartz - phyric Epiclastics

Quartz- phyric epiclastics ("massive pyroclastics") are the effective hangingwall rocks for routine drilling and exploration within the mine area.

6.2.3 Orebody - Form, Mineralogy, Zoning

Brathwaite (1969) documented Rosebery as a stratiform massive sulphide orebody, composed of a massive pyrite- chalcopyrite zone at the base of banded pyritic galena- sphalerite ore, then a separate, stratigraphically higher barite- sulphide horizon, which were subsequently folded and deformed to their present disposition. Green (1983) noted an increase in $\partial^{34}S$ from N to S in the orebody in concert with (Pb + Zn) / Fe ratio, which he regards as evidence for some lateral zonation of ore.

The mineralogy of the ore lenses is relatively simple for the major sulphide and gangue components, but a number of minor complex assemblages are due to metamorphism and metasomatism. Massive pyrite - chalcopyrite is usually overlain by a more extensive sheet of banded galena- pyrite- sphalerite ore. A separate, stratigraphically higher barite lens contains a higher proportion of galena to sphalerite than the lower lens, and pyrite. Minor phases occuring within the sulphide ores are described by Stillwell (1934), Williams (1960) and Huston and Large (1986).

Recent drilling has defined the distribution of ore lenses in the F lens and below the northern orebody, shown in a longitudinal projection (Fig. 43). Some general previously unreported features of the footwall stringer zone and ore lenses are described in the following section.

Stringer zone, footwall of F lens

In the footwall of F lens below 18 level, most of the fourteen drillhole intersections contain a pyrite - chalcopyrite - magnetite stringer zone within chlorite schist. The zone varies considerably, having intense pyrite - chalcopyrite - magnetite stringer mineralization in DDH 81R (13 metres of 4.9 % Cu with minor Au and Ag), but other nearby intersections have smaller widths of lower grade mineralization in sparse pyrite - chalcopyrite stringers with minor magnetite. In DDH 81R, small blebs of barite occur within the sulphide/ oxide assemblage.

The stringer zone is surrounded by unusually strong siliceous "quartz schist" alteration which is extremely pyritic in places. Occasional barite veins with minor sulphides and magnetite are present through the altered footwall pyroclastics in this area.

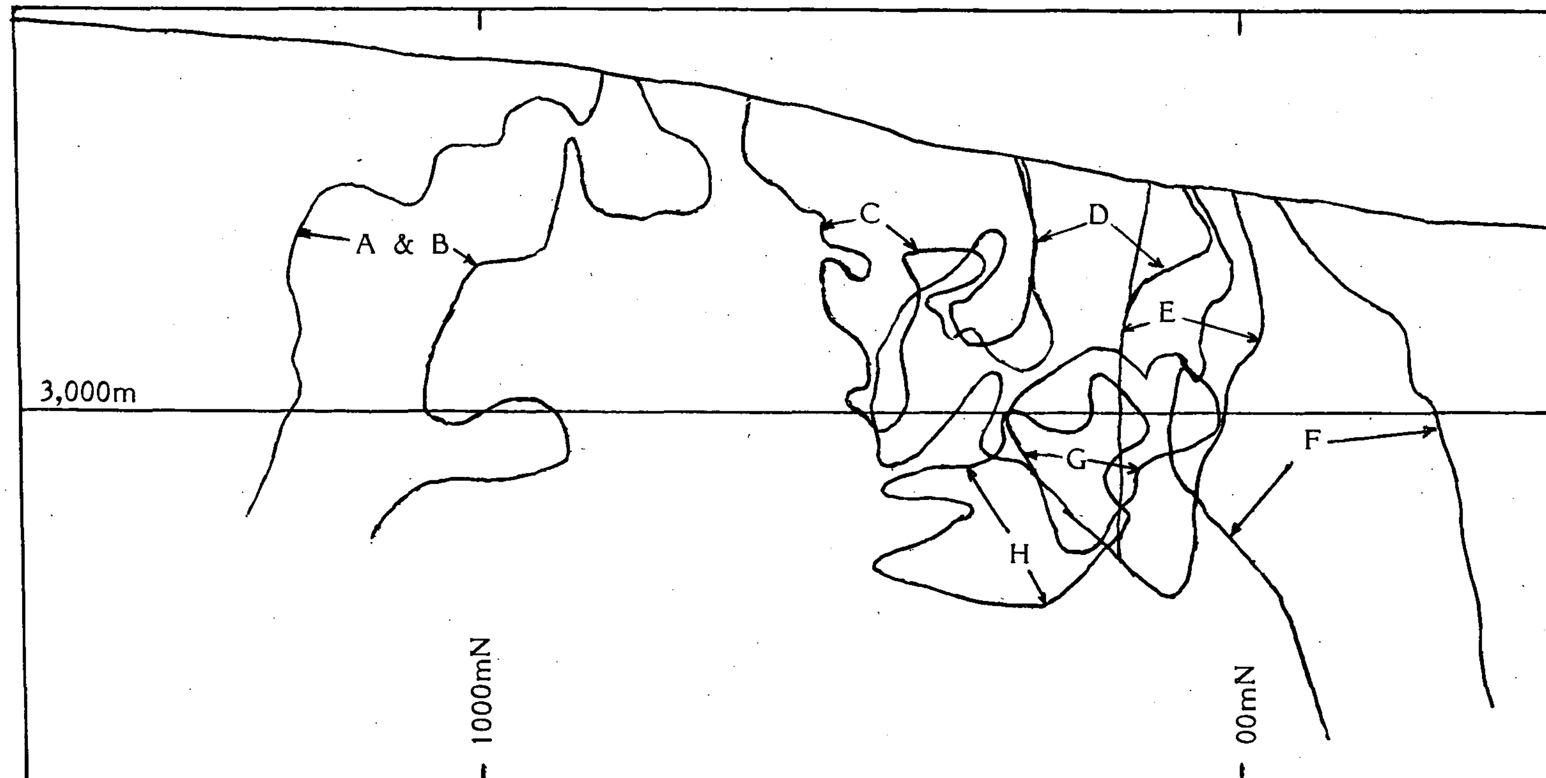


Fig. 43. Longitudinal projection of the Rosebery orebody.
Scale 1:10,000

A, B lenses (North end)

These were separate *en echelon* lenses in the old upper levels of the north end, but the complex structure has disrupted the main ore horizon into a number of lenses which are present in the current mine workings between 13 and 17 levels (and unfortunately this is termed C lens by the mine geologists, and is not differentiated from C lens further south).

Mapping and interpretation from drilling in this area (largely by mine geologist J. Howarth) shows complex structure dominated by rapid lensing of massive sulphides, and a series of NW striking faults having little displacement but seeming to control the distribution of ore lenses. Massive pyrite- chalcopyrite, often with minor chlorite, is overlain by the thickest pyrite-sphalerite ore, which may in turn be overlain directly by thick barite with minor sulphides. The peripheral ore zones usually have relatively thin pyrite- sphalerite ore, and a separate, stratigraphically higher barite horizon that is thin and without economic sulphides. The highest gold and silver grades appear to be concentrated in ore above the massive pyrite- chalcopyrite zones (G. Purvis, pers. comm., Huston and Large, 1986).

The north end mineralization is regarded as having been deposited on and around the hydrothermal vent, although no chloritic pyrite- chalcopyrite stringer zone is known. Naschwitz (1985) also regarded the north end as having its own hydrothermal vent, separate from the south end.

C lens

Little is known of C lens as it is mainly in the inaccessible upper levels of the mine. Information from old mine plans, and limited exposures in the open cut, show C lens to be a relatively simple sheet-like banded pyrite- sphalerite horizon. Small- scale folding and transposition has formed a number of adjacent sub- lenses.

A thin barite horizon may be present in the hangingwall of C lens.

D, E, G lenses

In the current part of the mine, 15 level and below, these lenses are strongly deformed with numerous examples of pronging and transposition of massive sulphide lenses. The lenses can only be distinguished in general terms, due to the locally intense disruption. D and E are overlapping lenses close to the base of the host rocks and probably close to their original position, while G lens represents a compressed and partly transposed fold.

The base of D and E lens is usually massive pyrite- chalcopyrite, which is directly overlain by masive pyrite- sphalerite ore. G lens is complex, and includes lenses of massive pyrite-chalcopyrite and barite amongst mainly pyrite - sphalerite ore.

F lens

F lens is a steeply plunging sheet-like body at the southern end of the mine. It is stratigraphically some 10 to 20 m above the footwall pyroclastics / host rock contact, but whether this slightly different position relative to the other lenses, which occur close to the contact, reflects a separate time- stratigraphic position, is uncertain. Stringer mineralization present in the deeper part of F lens is described above.

Massive pyrite - chalcopyrite lenses beneath the base-metal ore have an unusual habit of diverging from the ore, forming prongs which gradually peter out close to the footwall pyroclastics. The ore consists largely of sphalerite and pyrite with minor galena and chalcopyrite, which show evidence of recrystallization and annealing. Apart from the massive sulphide ore, a range of breccia- textured ores, consisting of chlorite and sericite and a wispy sphalerite veinwork, occur in the F lens area, and are interpreted as being products of remobilization during metamorphism. The upper part of the lens is commonly baritic, and no barite mineralization is present directly overlying F lens. Replacive pyrite- pyrrhotite- magnetite- tourmaline bodies are discussed later (Sect. 6.2.4). There is extensive faulting and disruption of F lens and surrounding rocks.

F lens directly overlies a pyrite - chalcopyrite - chlorite stringer zone, which presumeably was the vent for ore- forming hydrothermal fluids, at least for F lens. Pyritic galena-sphalerite at the base of F lens passes up into baritic ore without a break, perhaps indicating a compressed sequence here.

H lens

As shown by Brathwaite (1969), H lens lies stratigraphically above the other lenses. Barite is the main gangue, distinguishing this from the other lenses, otherwise pyrite and sphalerite with subordinate galena are the major minerals. Precious metal values in some parts of H lens peripheral to massive sulphide may be enough to make ore grade. Assays of between 150 and 300 g/t Ag, and up to 25 g/t Au, are not uncommon.

6.2.4 Pyrrhotite Replacement Bodies

Towards the southern end of F lens, a number of bodies of coarsely crystalline pyrite and pyrrhotite in varying proportions, and minor tourmaline, chalcopyrite and phlogopite, have definite cross-cutting and replacive contacts with massive layered galena - pyrite - sphalerite sulphide ore. The assemblages and paragenesis are described further in Section 8.5.1.

The pyrite - pyrrhotite bodies and surrounding rocks have been studied in detail on 16 and 17 levels at the southern end of F lens. Geological plans of these areas are presented in Figs. 44 and 45. Several related and often overlapping assemblages are present, characterised by the massive, granoblastic texture, and presence of schorl, phlogopite, and abundant Fe minerals as either sulphides or oxides. Fig. 46 shows zoned, euhedral schorl amongst coarsely

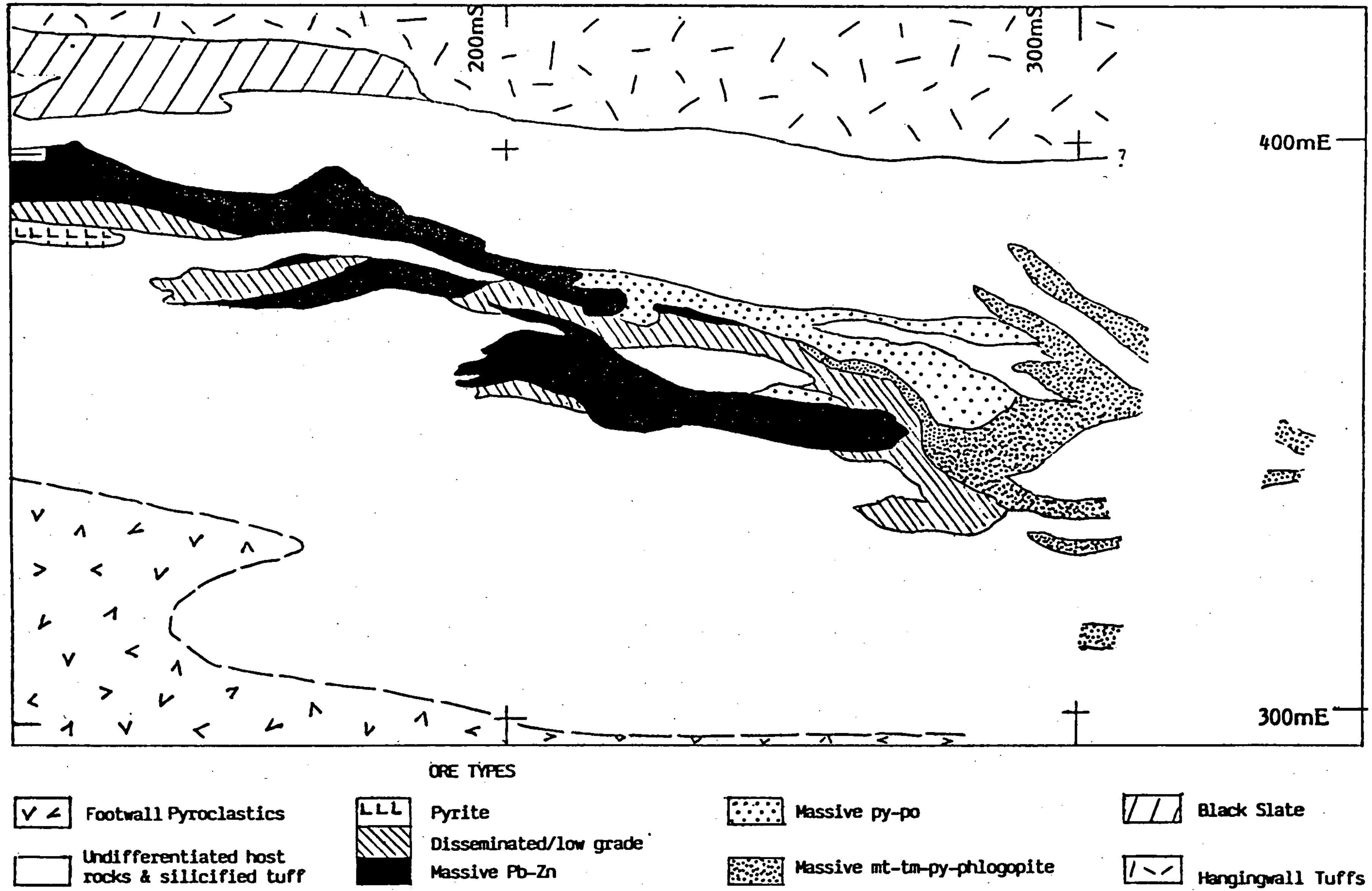


FIGURE 44 - Geological Plan, South End 16 level, Rosebery. Scale 1:1,000

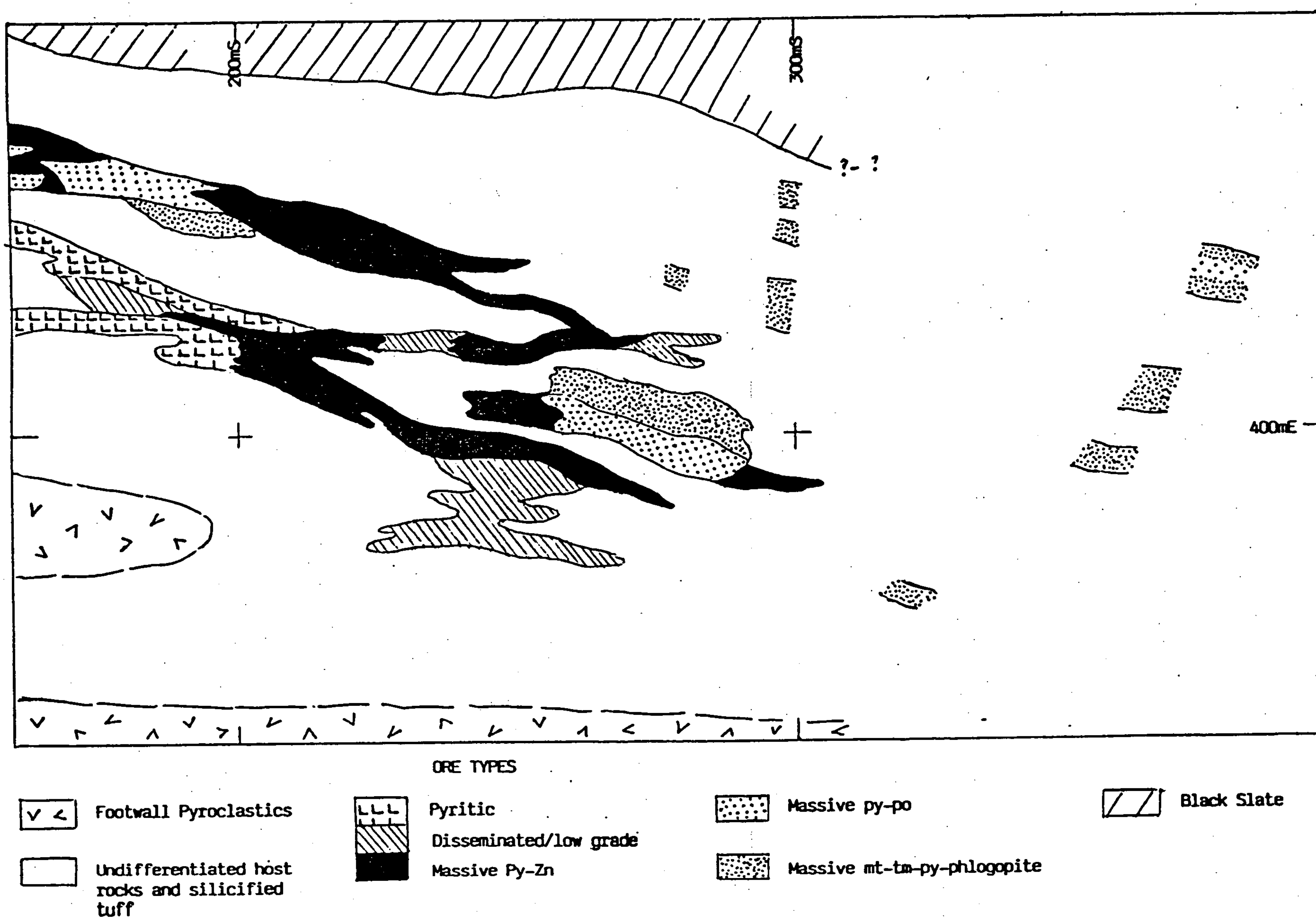
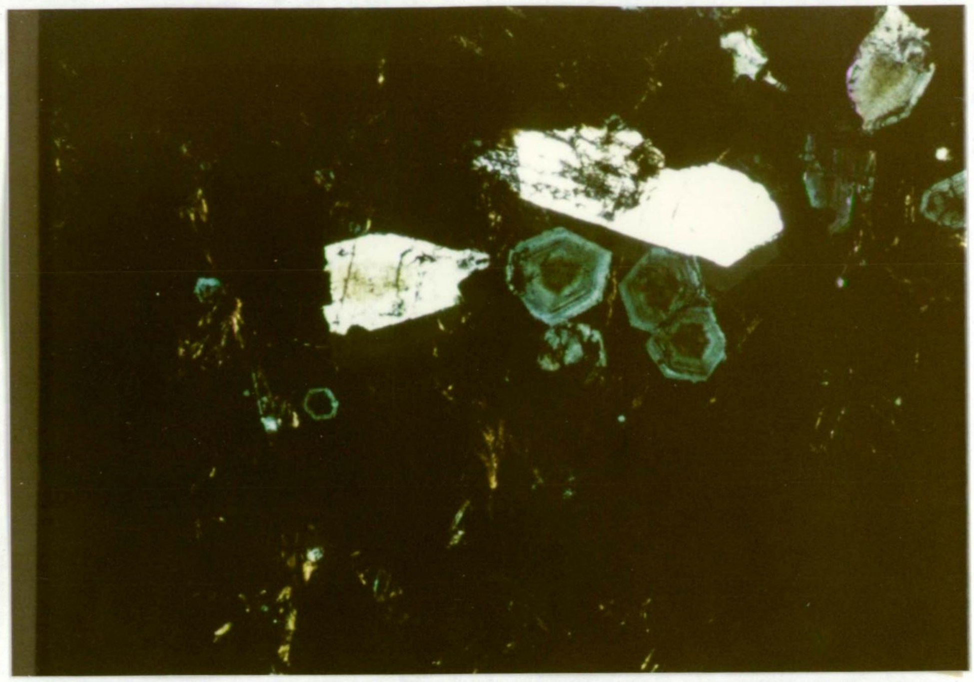


FIGURE 45 - Geological Plan, South End 17 Level, Rosebery. Scale 1:1,000



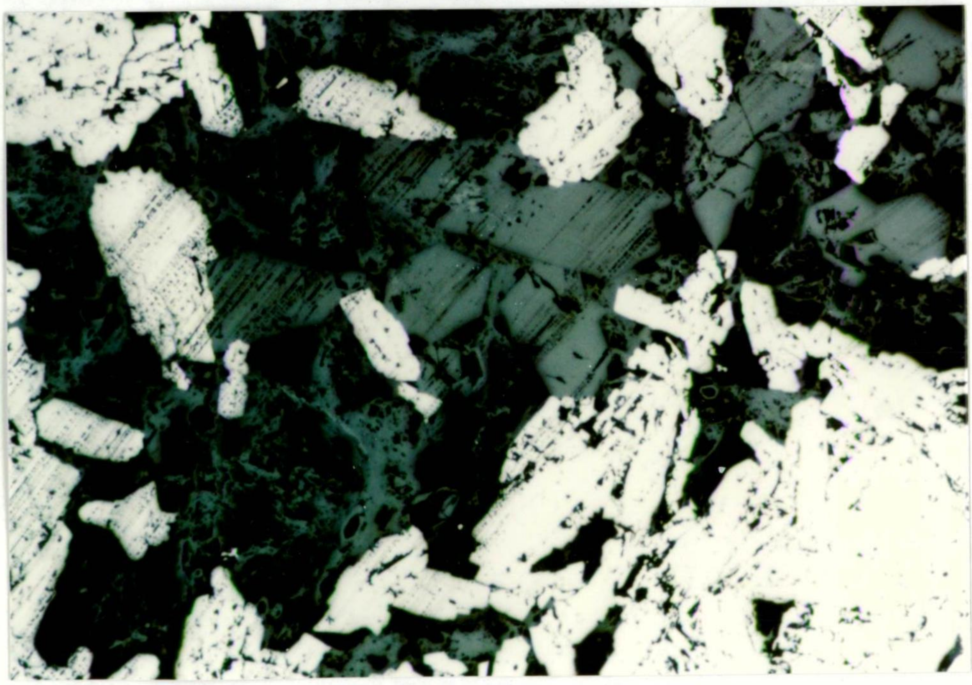


Fig. 46. Photomicrograph of schorl - magnetite assemblage, TS R 2971 77ft.
Above, XP light; below, reflected light.

1mm

crystalline magnetite, while Fig. 47 shows similar schorl with granoblastic pyrite.

In several localities in the mine, mapping has shown the pyrite - pyrrhotite contact to be transgressive to layering in the Pb-Zn ore. Brathwaite (1969), and Vokes (1983) show a replacement front invading folded Pb-Zn ore, indicating the replacement is post- folding. Outside the pyrite - pyrrhotite zone, a separate but related assemblage of massive magnetite-pyrite- tourmaline - phlogopite - chlorite - quartz forms an "envelope", comprising a number of irregular, cross-cutting zones through the host rock sequence. These show that the massive pyrite- pyrrhotite zone is present only where the magnetite- pyrite- tourmaline- phlogopite zone intersects what was massive Pb - Zn - sulphide ore. A thin transitional phase, comprising magnetite- pyrite- pyrrhotite, is often present. Tourmaline veining is usually prominent in the surrounding rocks.

Small crosscutting bodies composed largely of massive hematite commonly occur in baritic H lens only in the southern part of the mine, and although not studied, it is thought that these were also formed by replacement but the iron in replacing fluids, on encountering massive barite, was deposited as oxide.

6.2.5 Carbonates

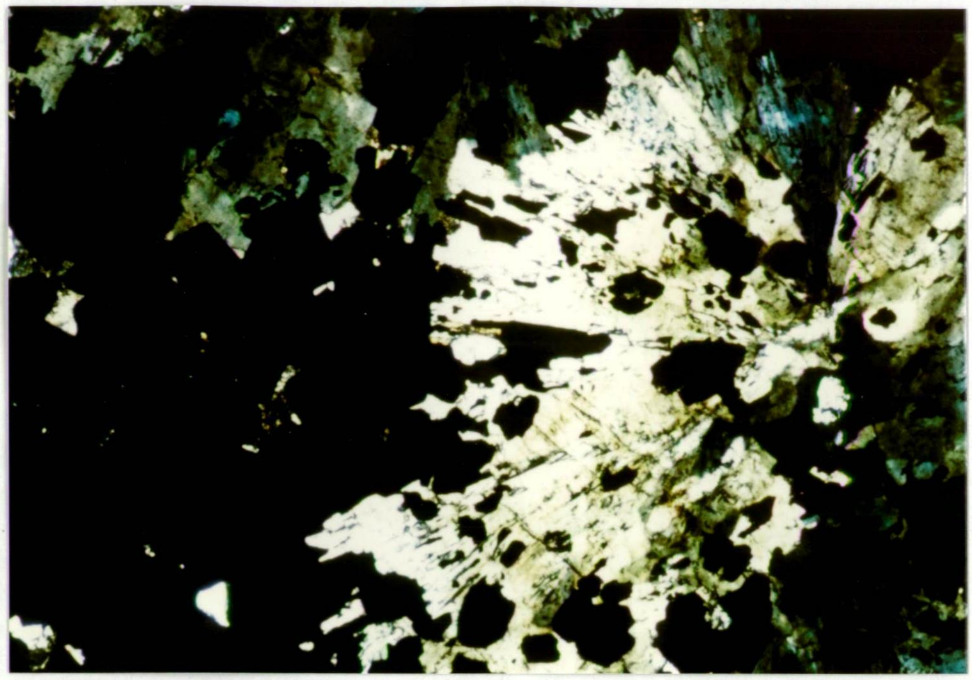
A variety of forms and mineralogy, have been discussed by Brathwaite (1969, 1974) and Green (1983), and were described in detail by Dixon (1980). Several of the forms appear to be closely associated with ore. In general, the carbonates form an Mn and CO_2 halo around the orebody.

Morphologies

The distribution of various types of carbonate is shown in Figure 48. Vague spots, grading to well- developed spheroids from 1mm to 5mm diameter ("oolites" or "pisolites" in mine terminology) form a halo around the orebody but are usually more concentrated and better developed beneath it. The "oolites" often coalesce to form larger, irregular pods close to ore, especially at the strike limits of any particular lens, and massive, recrystallized to botryoidal carbonates are often present at the end of a massive sulphide lens. Dolomite rhombs appear to be confined to the relatively unmineralized host rocks between the northern and southern groups of lenses.

"Oolites" are composed of concentrically layered but radially crystalline carbonate (Fig. 49). Internal variation in composition was noted by Dixon (1980). Apparently sedimentary structures, such as oolite - rich layers or beds, are sometimes folded, and fine to coarse grading of "oolites" within layers occurs sporadically.

Massive carbonate at the ends of the ore lenses is usually pink to brown, coarsely



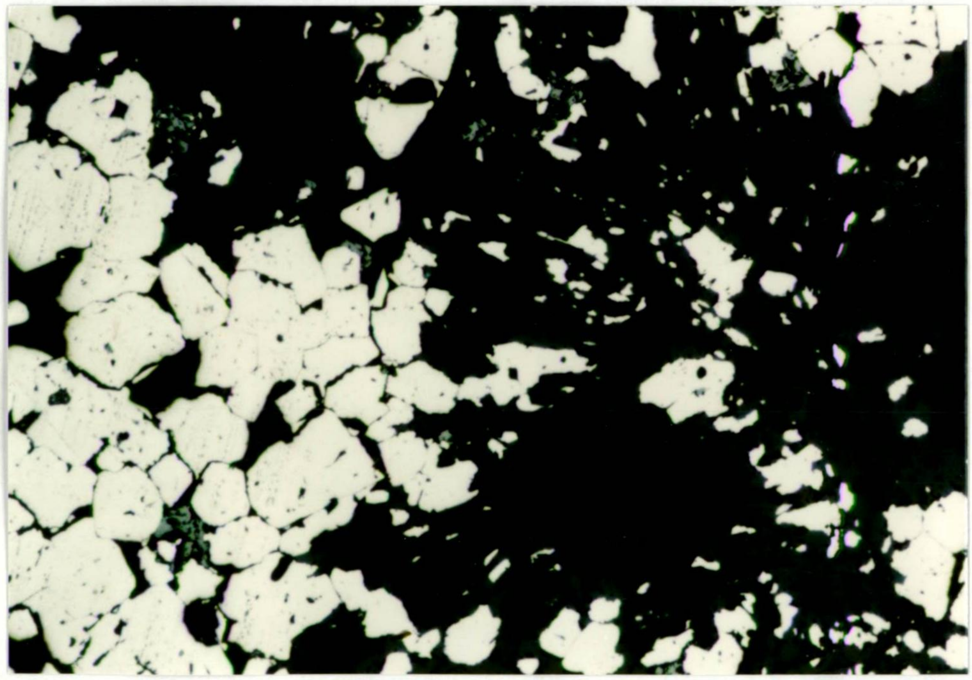


Fig. 47. Photomicrograph of schorl - pyrite asemblage, with radiating schorl aggregates, TS R 3016 225ft.
Above, XP light; below, reflected light.

1mm

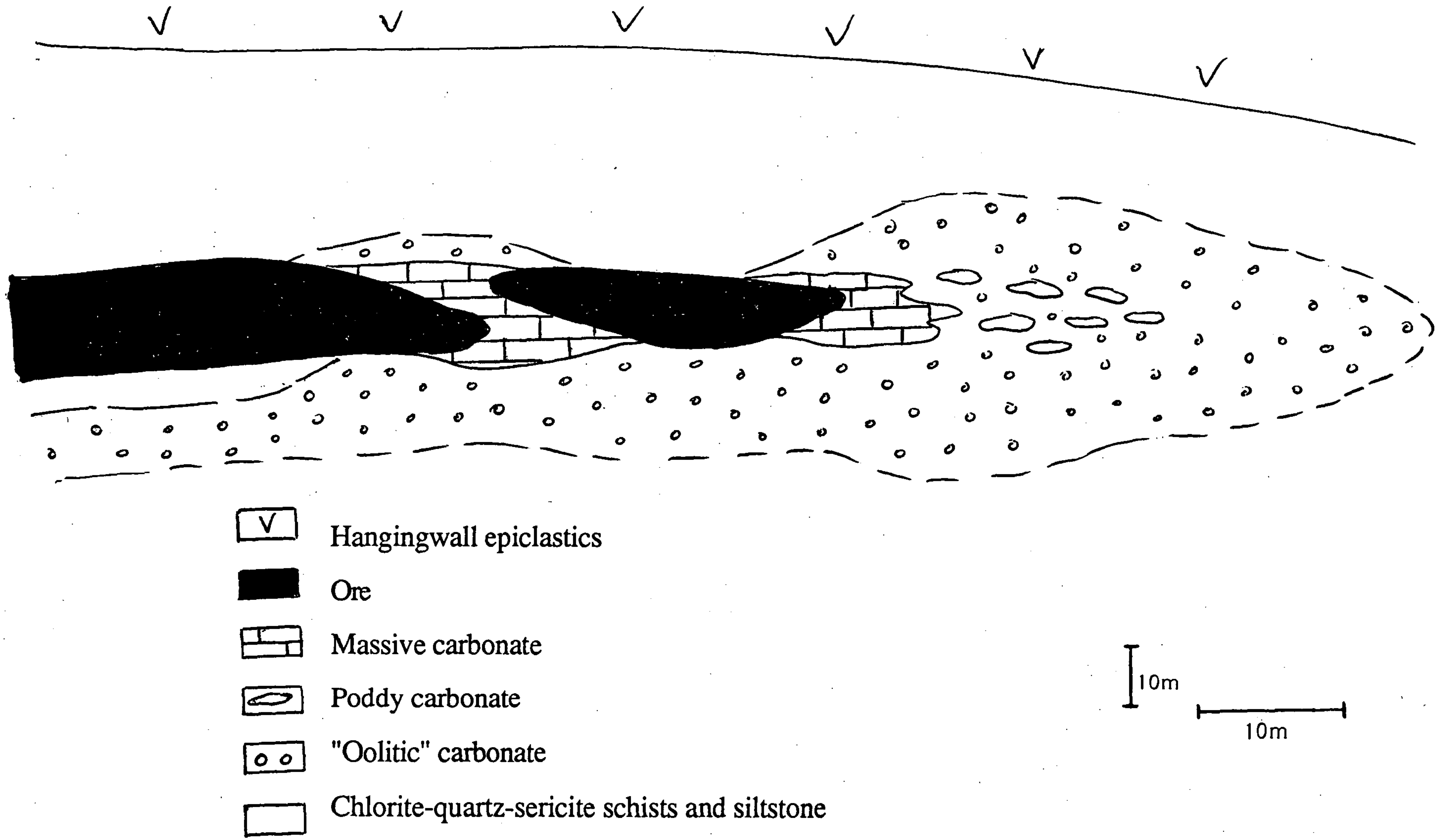


Fig. 48. Schematic distribution of carbonate types, Rosebery Mine.

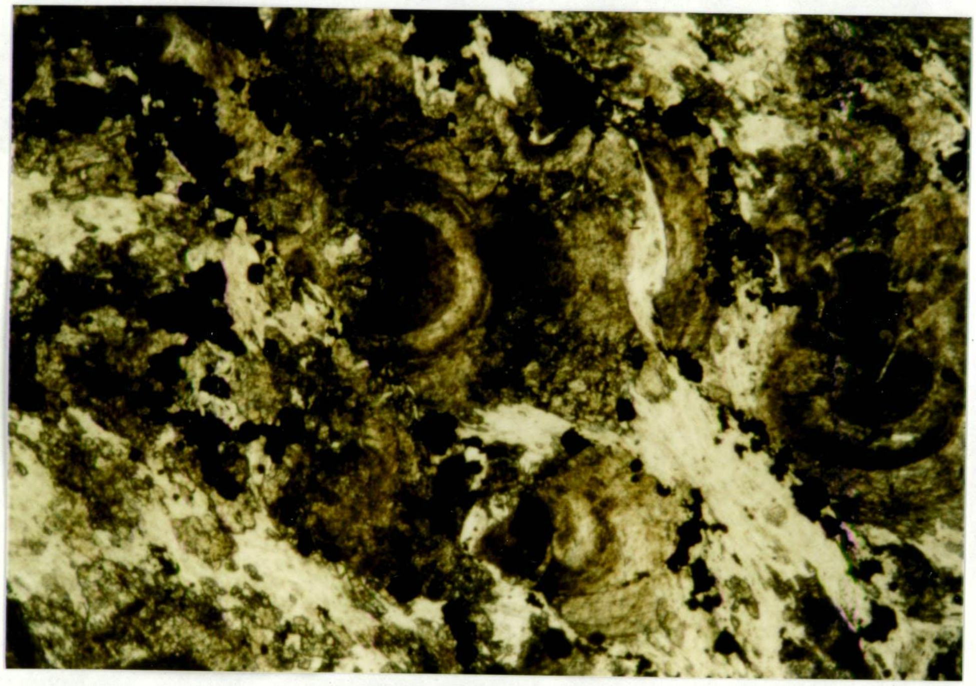


Fig. 49. Photomicrograph of carbonate spheroids, Rosebery, TS 55020.
pp light

1mm

crystalline and shows a variety of forms from packed, coalescing spheroids to colloform and sometimes botryoidal, and these features suggest the carbonate is deposited here in localised low- pressure area.

Within layered galena- sphalerite- pyrite ore small carbonate lenses are quite common, typically as 2 to 10 cm disrupted and folded lenses of finely crystalline carbonate, reported by Brathwaite (1969) to be rhodochrosite. The lenses often can be traced along layering in the ore, and in places comprise a 5% to 10% of the total ore thickness. These are interpreted as disrupted primary carbonate beds within the ore.

In the footwall pyroclastics, increasing alteration approaching the orebody is reflected in the carbonatization and smearing, with eventual destruction, of carbonate.

Late veins close to the orebody are of coarsely crystalline quartz, pink carbonate, chlorite and sulphides.

Carbonate Composition

Brathwaite (1969) found that carbonate in the "oolites" and pods was mainly rhodochrosite or ferroan rhodochrosite, while massive and vein carbonate was kutnahorite, and calcite and dolomite were uncommon.

Dixon (1980) found Mn and Fe in carbonate to be enriched in the footwall of F lens, and that the Mn and Fe content in carbonate, and the total carbonate content, decreases laterally away from ore.

Origin

Brathwaite (1969) considered most of the carbonates especially "oolites" and pods to have been precipitated directly from volcanic- exhalative fluids. Dixon (1980) proposed two models for carbonate formation; either it was deposited along- strike from ore by a now- depleted reversing buoyancy plume, or by lateral leakage or mixing of the depleted solution with seawater, with the mechanism for deposition being either boiling and loss of CO_2, or changing Eh - Ph - temperature conditions.

The distribution of carbonates, and their composition , have implications with regard to their origin. There is an obvious spatial relationship of carbonates with ore, which indicates a genetic link. Bringing the carbonates into the environment via the same transport system, but depositing them by a different mechanism, explains in general terms the close association but different habitat of ore and carbonate.

Assuming carbonate and ore were introduced by the same hydrothermal solutions, the depositional method must explain the distribution of carbonates both along strike and beneath the ore, as well as textures and composition. A diagenetic origin for at least some of the carbonate is possible, as explained below.

Dolomite rhombs in the barren gap between lens groups, were formed in unconsolidated sediments below the sediment / seawater interface, as evidenced by water escape structures disrupting a band of the dolomite rhombs.

The "oolites" show a variety of textures, some such as grading which tend to indicate a sedimentary origin, but others which may indicate nucleation and growth in a confined area. Resorbed margins of some, parallel growth structures in adjacent or interlocking bodies, and in one area (actually at Hercules, TS M 111) the "pisolites" have a nucleus of quartz, and rings of quartz at the same radius from the core of each.

Recrystallization and cavity-filling textures in massive carbonates indicate these are not primary carbonates, but were deposited in low- pressure areas at the end of each massive sulphide lens. Within each of the larger lenses, disruption of the original sulphide sheet has resulted in numerous, adjacent or joined smaller lenses, often with an envelope of massive carbonate at the junction. The massive carbonate thus appears to be related to the folding and transposition of the ore lenses. Brathwaite (1969) noted the difference in composition of massive and vein carbonate (kutnahorite, Ca, Mn $(CO_3)_2$) and the oolitic types of mainly rhodochrosite.

6.2.6 Genesis

Brathwaite (1969) established Rosebery as a stratiform volcanogenic massive sulphide deposit, but ideas on the formation of the deposit have changed little since then. Recent work, comprising core logging and expanding the mine 1: 1,000 scale cross - sections, combined with the results of Green's (1983) work, have enabled a modified version of a model for the Rosebery deposit to be presented in Fig. 50.

The orebody is underlain by an extensive quartz - sericite - schist alteration zone, but within this, in the footwall of F lens, is a chalcopyrite - magnetite-pyrite- chlorite stringer zone which probably represents a hydrothermal vent. Massive pyrite - chalcopyrite beneath sphalerite- pyrite banded ore probably represent smaller vent zones; in fact much of the deposit may have been formed above a large area of hydrothermal discharge. Above the F lens stringer zone, banded sphalerite - pyrite passes upwards into baritic ore, which can be traced laterally to a position stratigraphically above the lower sphalerite - pyrite ore.

Banded sphalerite - pyrite ore may have either been deposited as "sulphide rain", already hypothesized to form Rosebery-type deposits by Solomon and Walshe (1979), or by progressive direct precipitation of sulphides moving outward from a high - temperature hydrothermal vent, as proposed by Eldridge et al. (1983).

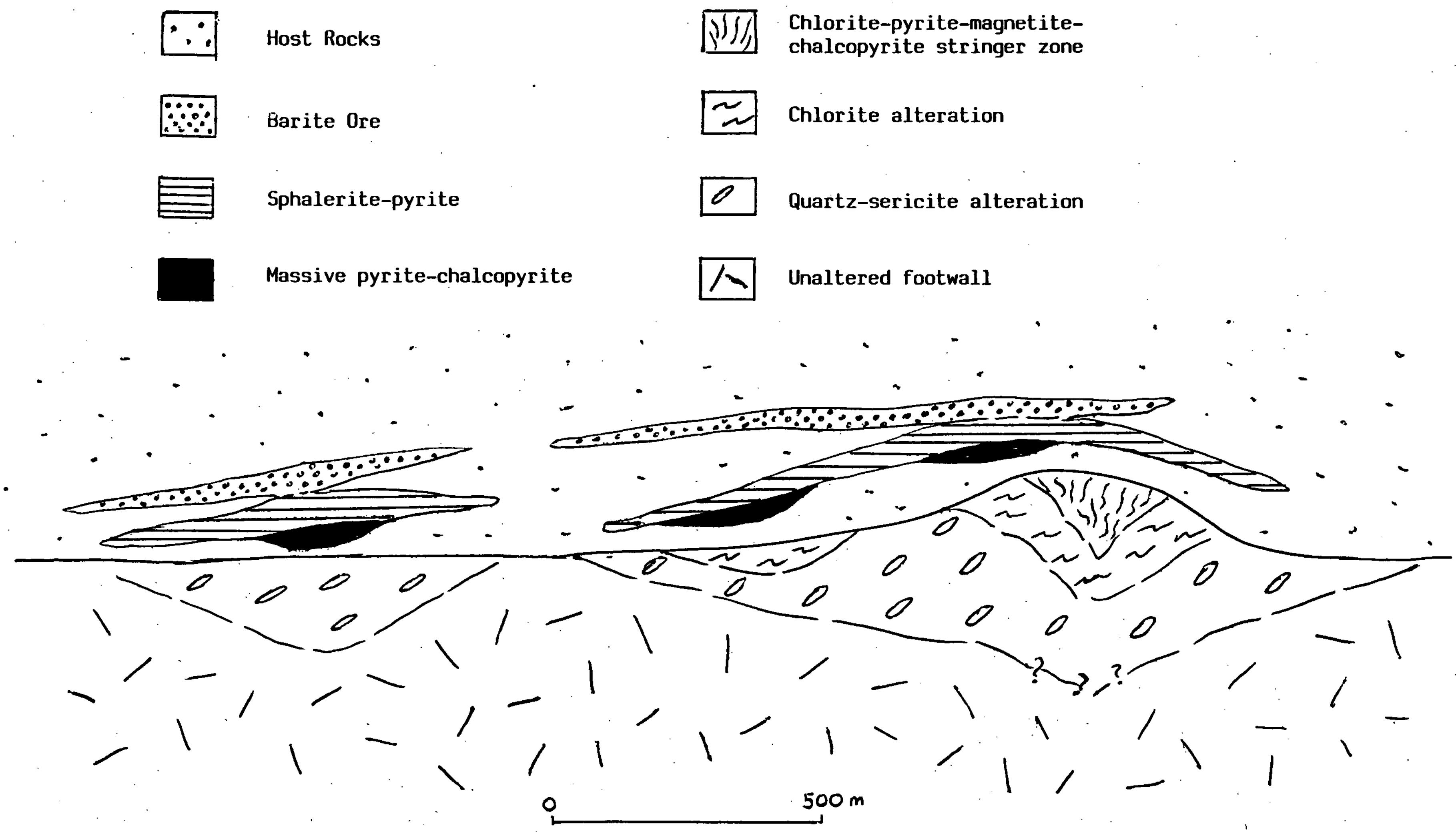


FIGURE 50 Model of the Rosebery Orebody.

6.3 ROSEBERY LODES

6.3.1 Introduction

At Rosebery Lodes, about 2 km south of Rosebery, a similar stratigraphic sequence to Rosebery hosts minor base- and precious- metal mineralization. Although in strict terms the host rocks are continuous between Rosebery and Rosebery Lodes, the Rosebery Lodes prospect area can be defined as extending from the S end of Lake Bull to Talune Creek (Plan 2).

6.3.2 Stratigraphy

The stratigraphy of the Rosebery Lodes area is shown in Fig. 51. There is considerable along- strike variation of units, with the thin mineralized intervals lensing out rapidly.

Footwall pyroclastics

Footwall pyroclastics consist of feldspar- phyric ash flow tuffs, which are altered to "quartz schist", below the mineralized zone. These are up to 30 metres of augen - textured silicified tuffs which thin and disappear to the north, and are of unknown extent to the south.

Host rocks

Altered footwall pyroclastics are overlain by 20 to 30 metres of "host rocks", consisting mainly of volcanogenic wacke with abundant quartz crystals and small lithics, which grade to volcanogenic siltstones and sandstones, and minor cherty pelitic to psammitic ash tuffs which occur at several stratigraphic levels usually close to mineralized horizons. Stratiform pyritic Pb - Zn occurs close to the base of the host rocks, while a stratiform barite horizon towards the top can be traced from hole to hole in some areas but is apparently absent in others. Carbonates are present surrounding areas of better mineralization, and generally increase in abundance toward the mineralization, from a minor phase altering feldspar and felsic lithics in volcanogenic wacke, to massive "oolitic" rhodochrosite near ore - grade sulphides.

The host rocks are known to extend southwards at least as far as drillhole RLP 275, but the overlying black slates are restricted to the northern part, but were probably originally more widespread as they were eroded and incorporated as lithics in the quartz - phyric tuffs.

Hangingwall

Above the host rocks, 10 to 20 metres of black slate with lithic wacke and volcanogenic sandstone, and further black slates in places, are overlain by quartz- phyric lithic tuffs with siliceous and shale lithics concentrated in basal lithic- rich zones.

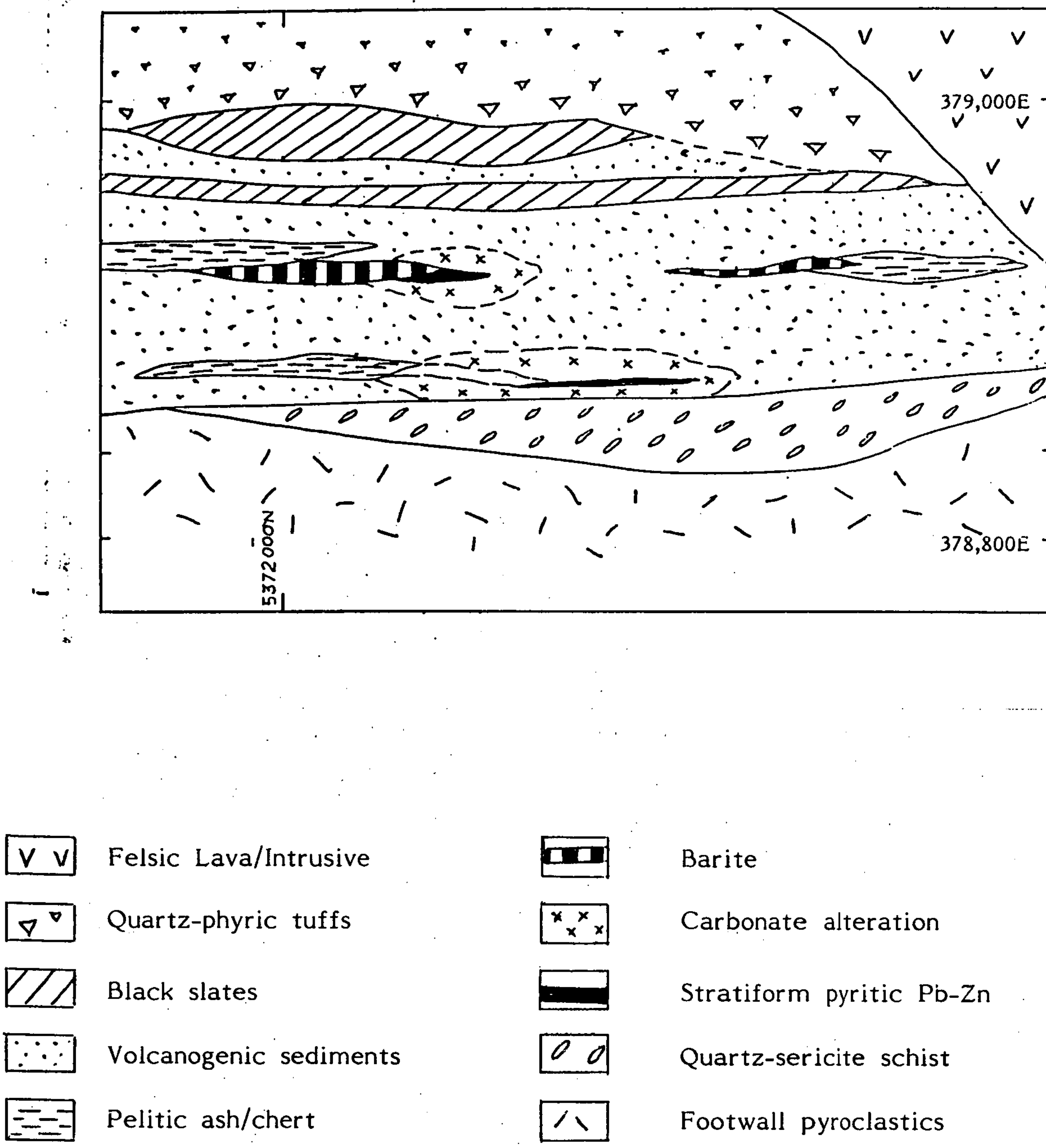


FIGURE 51 - <u>Generalised section of the Rosebery Lodes area</u>

In the southern part of the area, an altered and weakly mineralized lava or pitchstone overlies pelitic to psammitic ash tuffs, and is usually followed by massive, relatively unaltered lavas, so that it could be considered as part of the host rock sequence. A similar altered lava (?) was intersected at the southern end of the Rosebery host rocks in drillhole 73R, at a similar stratigraphic position. The quartz- phyric tuffs thin markedly to the S, and lens out, so that rhyodacitic to dacitic and andesitic lavas and hyaloclastites of the Mt. Black Volcanics overlie the host rocks and equivalents.

6.3.3 Mineralization

During the 1970's an extensive program of short drill holes was designed to test an outcrop of high Ag- barite within host rocks. The best intersection was in RLP 155, with 4ft at 4.9% Zn, 0.3% Cu, 250 g/t Ag, 2.25 g/t Au, 11.0% Fe. Other results include short intervals at somewhat lower grades.

Pyritic Pb - Zn at the base of the host rocks is extremely thin and restricted in area, but in RLP 159 is 0.3 m. of 7.2 % Pb, 7.4 % Zn, 106 g/t Ag, 0.15 g/t Au. Weaker mineralization is present along strike.

A stratigraphically higher zone of mineralization contains locally abundant barite, and associated anomalous Au and Ag, as in RLP 146, with 3ft at 0.7%Zn, 0.1%Pb, 208 g/t Ag, 0.84 g/t Au and 10.5% $BaSO_4$. This mineralized zone can be traced for a considerable distance along strike, initially through the presence of sulphides and barite, then further by anomalous geochemistry of Pb, Zn, and particularly Au which is enriched to > 0.1 ppm.

At the southern end of the prospect, in drillhole RLP 275, a chlorite- pyrite- chalcopyrite stringer zone some 3 metres thick lies at the footwall pyroclastic - host rock contact, but apparently there is no stratiform base- metal mineralization directly associated with this hydrothermal vent.

6.3.4 Genesis

Similarities in the stratigraphy, mineralization and alteration styles between Rosebery and Rosebery Lodes suggest a common origin for these deposits; Rosebery Lodes being a smaller edition.

The basal pyritic Pb- Zn horizon was deposited just above the footwall pyroclastics - host rocks contact, by hydrothermal fluids mixing with seawater above the seafloor. Alteration of the "footwall pyroclastics" to quartz- sericite schists, and carbonate alteration and replacement of host rocks accompanied mineralization.

The baritic Pb - Zn - Ag - Au horizon was presumeably deposited somewhat later at lower temperature, again accompanied by carbonate alteration and replacement.

6.4 HERCULES

6.4.1 Introduction

The Hercules orebody lies on the flank of Mt. Hamilton (1,007m) some 7 km south of Rosebery, above the now demolished township of Williamsford. Discovery of the orebody is attributed to A. E. Conliffe who pegged ground around the old Mt. Read mine (subsequently L-M lodes, Hercules) in 1891, but the gossan outcrops further north were not discovered until 1894.

Available records show that, when production ceased in August, 1986, a total of 2.3 Mt had been mined at an average grade of 5.5 % Pb, 17.3 % Zn, 0.42 % Cu, 172 g/t Ag and 2.8 g/t Au.

The following discussion is adapted from Lees (1985) and Lees and Howarth (in press), which were produced as a result of recent work in the area. Previous work on the deposit includes Hall (1967), Fitzgerald (1974) and Burton (1975b). Cross sections at 600'N and the 5 level plan of ore lenses are shown in Figures 52 and 53 respectively.

6.4.2 Stratigraphy

The sequence in the immediate mine area may be summarized as follows:-

Top	Lithic tuff- with black slate fragments, quartz phenocrysts.
	Black slate.
	"Host rocks"- subaqueously deposited ash tuffs
Base	"Footwall pyroclastics"- welded (subaerial?) fiamme- bearing feldspar-phyric ash flow tuff, with overprinting siliceous alteration.

The sequence is right-way-up, because of the presence of black slate (and other) fragments immediately overlying the black slate, and occasional sedimentary facings (graded beds, scours) within the shales south of Hercules. Relationships are complex and in many cases demonstrably erosional, as is to be expected in an active volcanic environment.

Footwall Pyroclastics

The footwall pyroclastics are well exposed in the mine workings and northward along Copper Ridge. In the mine area they are altered, and consist of chloritic, pyritised fiamme in a siliceous matrix. Feldspars have been obliterated. A coarse, agglomeratic phase is

A3-502-0167

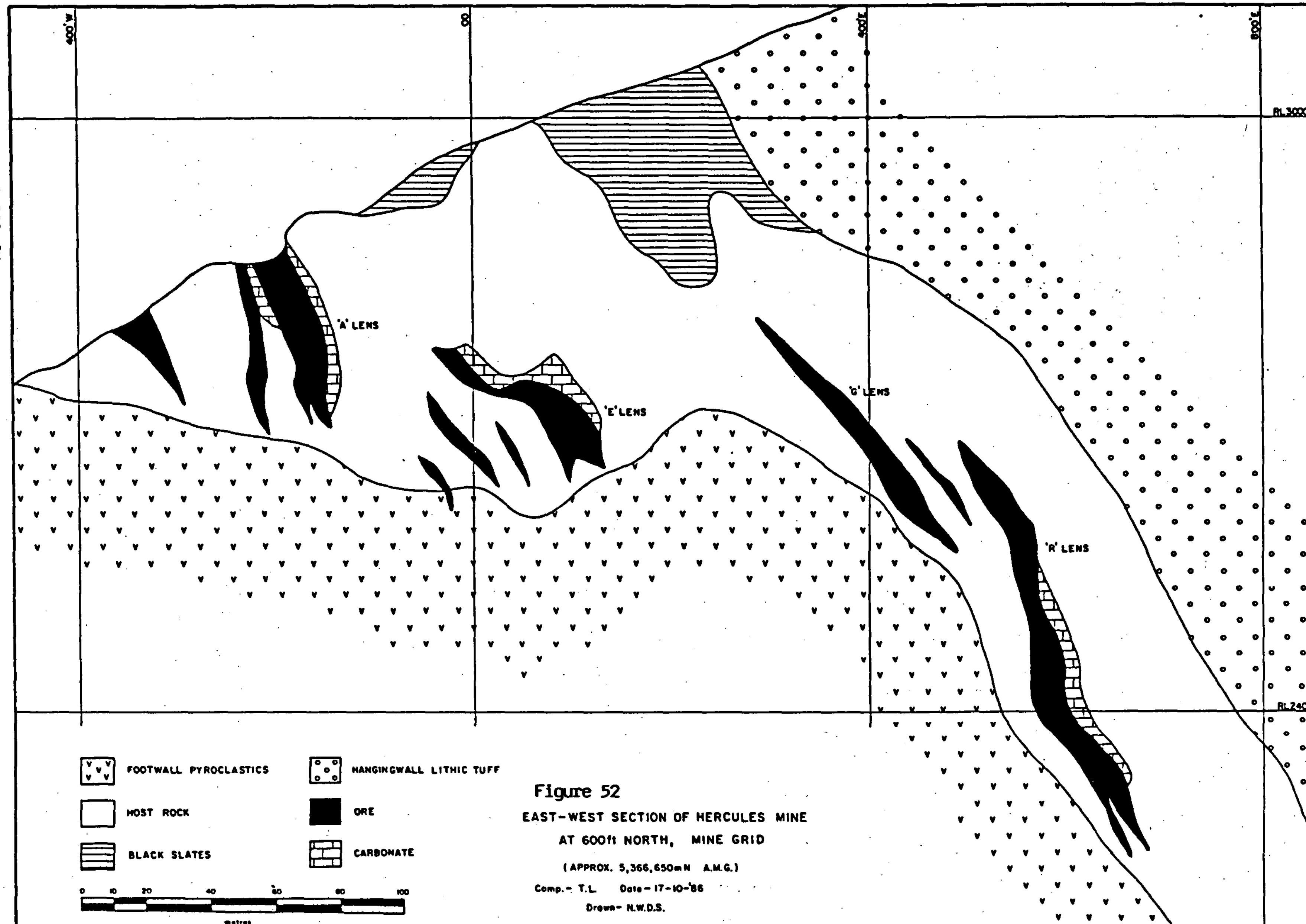


Figure 52

EAST-WEST SECTION OF HERCULES MINE AT 600ft NORTH, MINE GRID

(APPROX. 5,366,650mN A.M.G.)

Comp.- T.L. Date- 17-10-86

Drawn- N.W.D.S.

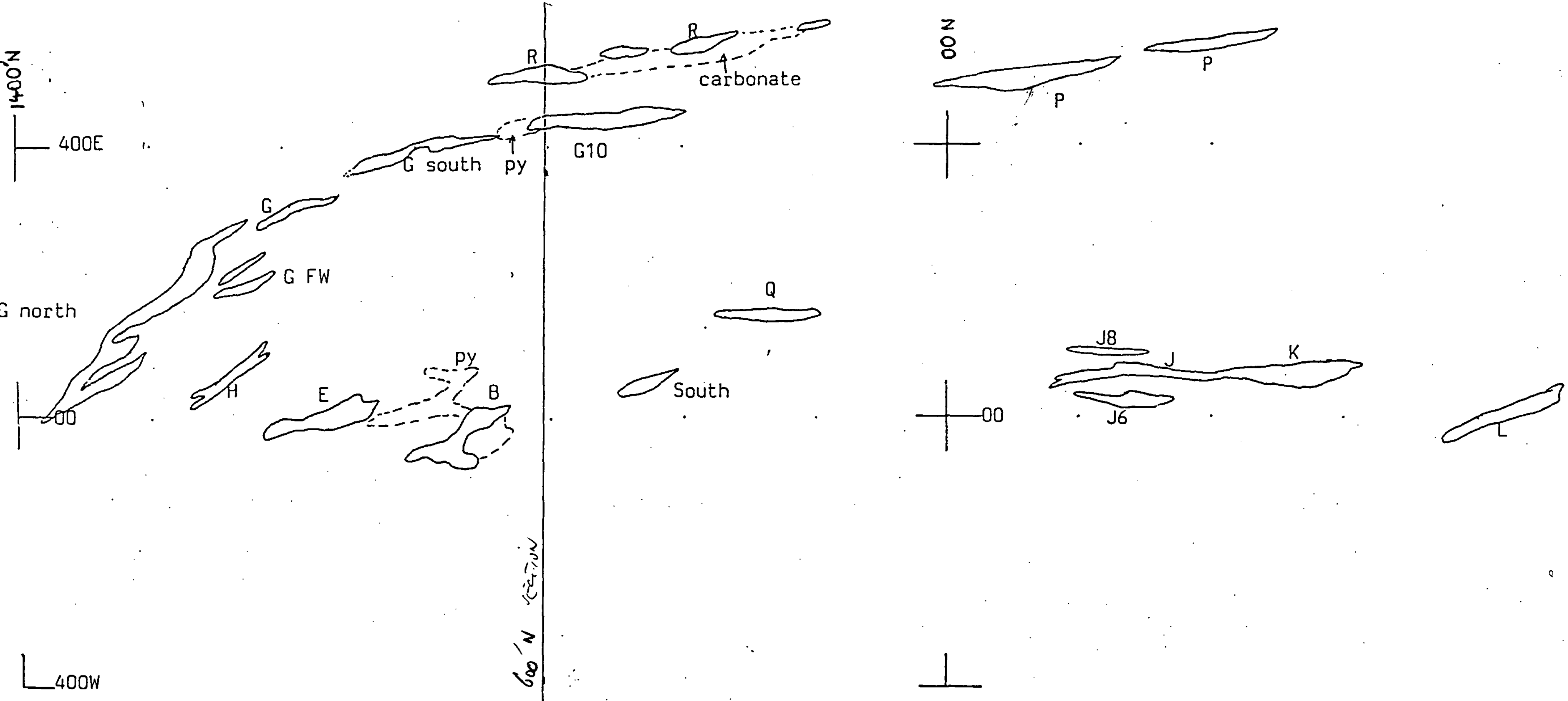


FIGURE 53 - HERCULES 5 LEVEL PLAN Scale 1:2,500

sometimes present at the top of the footwall pyroclastics (Fig. 14), consisting of coarse, siliceous fragments and pumice.

The equivalent rock outside alteration consists of sericite- chlorite fiamme in a pink felsic groundmass with vague felsic lithics and feldspar crystals.

Near the contact of footwall pyroclastics and host rocks, alteration becomes intense, and, in the extreme, forms a siliceous breccia with sheared chlorite wisps representing original fiamme.

Host Rocks

In the Hercules mine area the "host rocks" are approxiamtely 100m thick, and although folded, have an overall dip of 20 - 30° east.

The Mt. Hamilton Fault supposedly trucates the host rocks to the east at the northern end of the deposit, but there is evidence from deep drilling (namely H704 and H710) that host rocks continue to dip flatly to the east. The northern termination of the host rocks is complicated by faulting, but the trace of the host rock horizon (as distinguished in mapping of feldspar-phyric footwall rocks versus quartz- plus feldspar-phyric hangingwall rocks) continues to dip east around the northern flank of Mt. Hamilton. Folds in black slate at the north end of Hercules indicate a closing south- plunging synform.

The host rocks consist of poorly bedded psammitic to pelitic reworked ash tuffs and tuffaceous sediments. Main components are quartz, variably carbonated feldspar, and felsic tuff and lava lithics, in sericite- chlorite matrix. A feature of these rocks is the amount and types of variously textured carbonates present.

Diagenetic nodules of intergrown quartz and carbonate are common in unmineralized host rocks. These are from 1cm to 15 cm diameter "cannon- balls" and bedding can sometimes be traced through them although cleavage often wraps around them.

Carbonate "pisolites" are common in a halo around the ore lenses. These are spheroids from 1 to 10 mm diameter, usually composed of concentric layers of manganiferous or Fe - bearing carbonate, although some have quartz layers within the structure. The "pisolites" are often tightly packed (Fig.54), especially when close to ore, and are seldom more than 10m from ore - grade mineralization. Their origin is related to ore formation, and some speculations on their origin are made later. Dolomite rhombs are known but are of limited extent, and "fireworks textures" of radiating carbonate needles have been noted by I. McNaught (pers. comm. 1984).

Massive recrystallised carbonate occurs close to ore. Relict oolitic structures are often present in pink to brown complex Ca, Mn, Fe-bearing carbonate. Colloform and botryoidal textures have also been noted. Quartz - rhodochrosite veins were formed during deformation and remobilisation of quartz and carbonate.

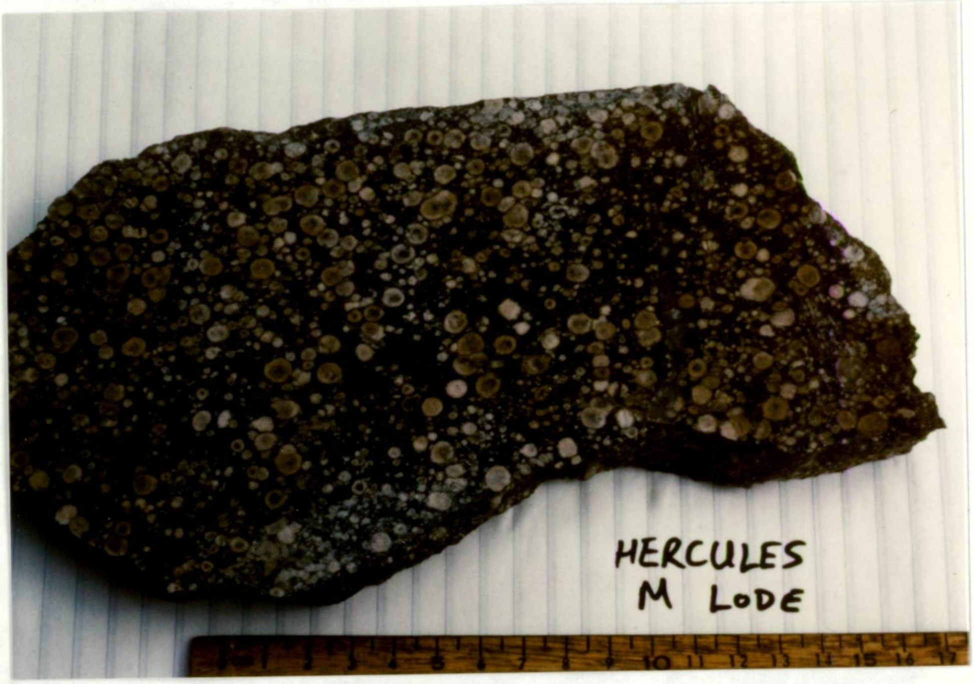


Fig. 54. Packed carbonate spheroids, M lode, Hercules.

Black Slates

Thinly bedded black slates with thin lithic wacke bands and minor other clastics, overlie the host rocks. Pyrite, as disseminations, bands and nodules, is locally abundant. Near the top of the slates, a quartz - feldspar wacke or sandstone thickens and gradually changes southwards into a lithic wacke, sometimes with a lithic-rich base.

Lithic Tuff

Overlying the shales are lithic - crystal tuffs with black slate fragments and quartz crystals in a siliceous matrix. The base is often lithic - rich and the clast component often drops off very rapidly upwards.

The unit is quite strongly silicified and variably chloritised and is often only distinguished from footwall pyroclastics in thin section where quartz phenocrysts are still discernable. The alteration is centred on the East Hercules area, where chlorite - pyrite - chalcopyrite mineralization may be associated with discordant felsic lava/intrusive. Alteration in these lithic tuffs decreases southwards away from the intrusive.

6.4.3 Ore Lenses - Morphology and Zonation

The Hercules orebody consists of a number of lenses which are, in most cases, joined at some point to the neighbouring lens. In plan, the ore lenses are distributed in a wedge shape, with the bunched pods of B, C, D, E and F lenses forming the apex, and two sub- parallel lines containing the remaining lenses separating to the S. The western line contains A lode, J-K lodes, M, L, and R lodes, and continues to South Hercules, while the eastern line contains G, R and P lodes (Fig. 53).

The lenses vary form sheets to pods but have an overall consistent east dip of 70° E, which is parallel to cleavage but not to bedding, and are in places demonstrably intrusive into the host rocks and black slates.

Several ore - types have been recognised, and each lens (except G lens) consists of several types. G lens is peculiar in being the main barite lens and varying only in the proportion of its' constituents.

Most lenses are "zoned" from a Pb-Zn rich massive sulphide core, to a chalcopyrite - pyrite - rich tail (see Fig. 55). The siliceous chalcopyrite - pyrite - rich zones separate, thin and disappear with depth. Typical of this type of zoning are the bunched pod - like ore lenses (B, C, D and E lens) at the northern end of the deposit; but all lenses exhibit this feature to a greater or lesser degree.

G lens may be more complicated- as well as showing the chalcopyrite - pyrite rich base in places, the top of the lens, and some baritic lenses in the footwall of the major G10 lenses, are Au- Ag rich.

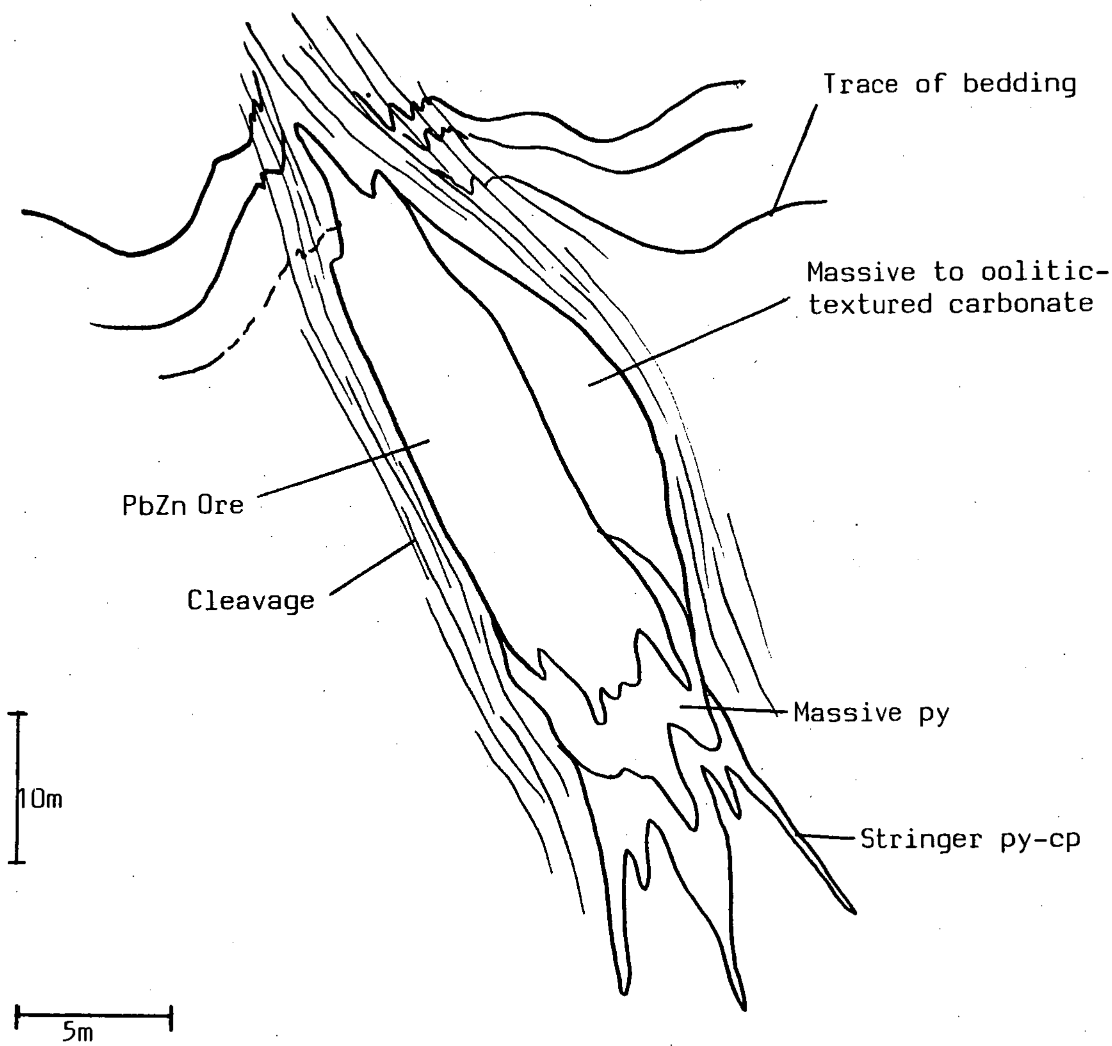


Fig. 55. - Generalised zoning pattern of the Ore Lenses at Hercules

The Pb - Zn ore lenses commonly have a "halo" of carbonate-rich rocks, composed of packed "oolites", recrystallised, massive carbonate, or, more rarely, colloform carbonate. These types are never seen more than a few feet from ore. Although not studied in detail, the amount and composition of carbonate may also be a guide to ore; the carbonates close to ore are often pink or brown, reflecting a high Mn- Fe content. A similar conclusion was found for carbonates at Rosebery by Dixon (1980).

6.4.4 Ore Lenses - Grades

Table 2 shows a range of assays and grade variations typical of the main lenses, selected from averaged drillhole intersections.

The group of coalescing lenses at the north end of the deposit of B, C, D, E and F lodes are typified by high grade, massive sulphide pods with variable grade but Zn usually much greater then Pb, Cu is less than 1 %, and Ag and Au grades are variable (eg. drillholes H396, H657, H7, H689, H690 in Table 1). Massive pyrite below the Pb - Zn ore in E lens is typical of the lens zonation, and contains minor sphalerite in massive pyrite (36 % Fe) with chalcopyrite (3 % Cu), and is followed by thinner chalcopyrite- rich stringer zones with up to 8 % Cu and minor Au and Ag (eg. H324).

A lode consists of a number of small pods on the western line of mineralization. High grade pods of porphyroblastic sulphides are surrounded by lower grade "spotty ore", which together form mineable tonneage and grade in the A lode open cut, at a lower than average ore grade (eg. H276).

Further south, two coalescing lenses with a number of smaller lenses, are J and K lodes, which consist of massive sulphide with usually high but erratic grades. Zn is as usual significantly higher than Pb, and Cu- rich sections are usually confined to the lower part of the lens (eg. H610, H508, H1072). On the continuation of this line of lode, narrow but in places high grade mineralization in L, M, and N lodes (eg. H31, H376) does not persist at depth, and has only been mined in a few areas where particularly high grade, or where extractable by open- cut mining.

The eastern line of mineralization consists of three separate main lenses (G, R, P) but these may themselves be composed of smaller lenses, or have smaller lenses nearby.

G lens is barite-rich at the northern end, and here contains consistently high but erratic Au and Ag (eg. H175, H672). In general, Au and Ag with associated barite decrease southwards in the lens, and Cu increases. Although Cu- rich areas are present, especially at the base of the southern part of the lens (eg. H108, H943), very little massive pyrite with minor chalcopyrite ore occurs in G lens.

R lode is offset some distance into the hangingwall of G lens (relative to the orientation of the lenses) and south of it. Main ore types in R lode are sheared, sericitic ore and "spotty ore", with minor massive sulphide, which accounts for the lower grades. Au and Ag contents are generally low. The grade of R lode generally shows a progressive decrease down- dip, without either a massive pyrite or pyrite-chalcopyrite stringer zone present (eg. H831, H1016).

Further south, P lode consists of several lenses of mainly "spotty ore", with minor thin bands of high grade porphyroblastic sulphides, and this is reflected in the generally low grades (eg. H760, H780).

Table 1. Typical assays of various lenses at Hercules. Data from drill hole logs, assays by EZ Rosebery Lab. N = not assayed.

DDH	Lens	Width (ft)	%Pb	%Zn	%Cu	g/t Ag	g/t Au	%Fe
H 396	B	34	2.9	18.0	N	45	0.8	N
H 657	C	29	4.8	25.8	0.6	530	1.0	11.9
H 7	E	40	8.6	39.1	0.5	120	3.1	N
	E	47	4.9	23.9	0.26	150	2.9	N
	E	34	1.8	43.5	0.5	120	3.1	N
H 324	E	9	N	N	8.2	37	0.3	N
	E	6	N	N	5.7	34	2.5	N
	E	10	0.4	4.5	3.0	59	0.4	36.0
H 689	F	11	4.1	8.4	0.2	71	1.4	6.3
H 690	F	12	0.8	16.9	0.6	15	0.4	13.5
H 276	A	30	1.2	12.9	1.1	32	0.4	N
H 610	J	50	6.8	10.4	0.2	274	1.7	N
H 508	K	17	8.9	27.1	0.26	280	1.5	N
H 1072	K	30	1.6	6.4	0.5	23	1.1	N
H 31	L	42	12.1	22.1	0.74	360	7.2	N
H 376	N	16	9.1	15.0	0.57	75	0.3	N
H 175	G north	18	18.9	31.7	N	580	20.0	N
H 672	G	38	3.2	9.5	0.24	243	4.5	16.2
H 108	G	31	1.9	23.9	0.7	74	2.7	N
H 943	G 10	42	0.7	4.6	3.2	48	N	21.5
H 831	R	20	3.5	13.6	0.2	58	4.9	6.6
H 1016	R	29	1.3	1.5	0.06	30	0.5	2.2
H 760	P	40	2.0	11.9	0.3	30	1.4	N
H 780	P	30	0.2	5.4	0.9	22	0.3	N

6.4.5 Ore Types

A variety of ore types have been recognised, based on texture and mineralogy. Most ore is recrystallised and porphyroblastic, and only G lens consists of finely laminated pyrite-sphalerite ore that is typical of Rosebery.

Porphyroblastic Ore

This type of ore is highly variable in grade and mineralogy, and is characterized by its obvious porphyroblastic texture. It is widespread, occurring in all lenses with the possible exception of G lens, and constitutes a large proportion of the ore from Hercules.

Porphyroblastic ore typically consists of recrystallized sphalerite in porphyroblasts from 2 to 20 mm diameter, surrounded successively by a thin rim of galena, usually intergrown with pyrite and/or chalcopyrite, a selvidge of muscovite and quartz crystals, and silicate gangue forming the matrix or filling the interstices between porphyroblasts (Fig. 56). Galena - sphalerite boundaries are usually curved to cuspate, indicating post-ore annealing of the sulphides. Pyrite euhedra may be scattered through the sparse chloritic, sericitic or siliceous matrix.

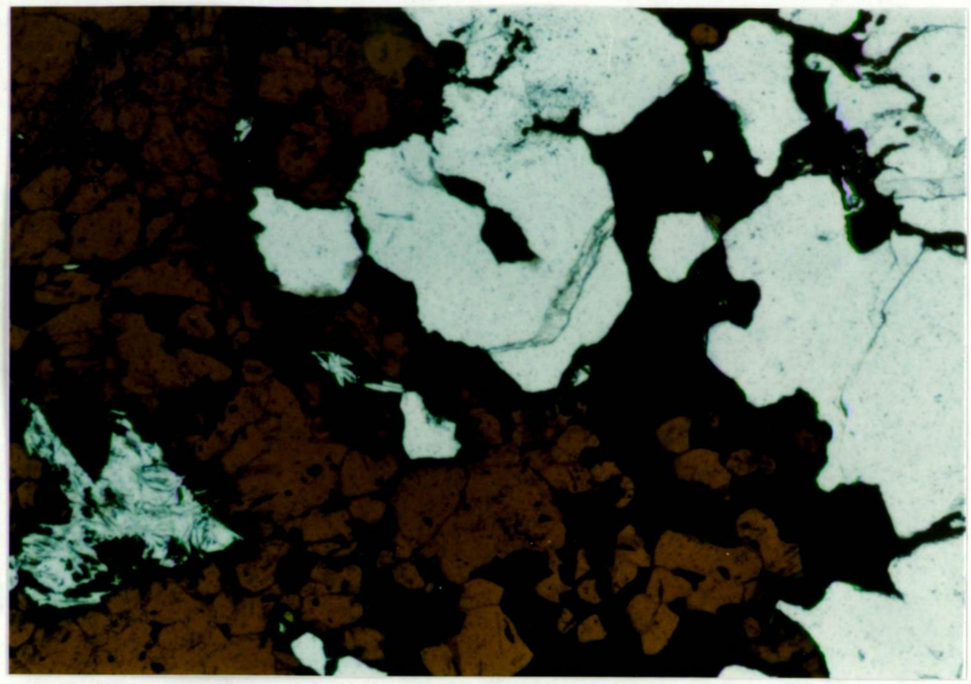
Spotty Ore

A variant of porphyroblastic ore, locally called spotty ore because of its appearance, occurs in most lenses, peripheral to the higher grade porphyroblastic ore. In detail, the ore consists of 2-5mm diameter spheroids to flattened ovate "spots" of sphalerite, or occasionally galena, rimmed by muscovite sheaves, then crystalline quartz and an outer rim of pyrite, in a spherulitic siliceous matrix with minor fine sericite, and welded tuff fragments (Fig.57). The elongate sphalerite spots usually have "pressure shadows" at the distal ends of the spots, of intergrown galena and chalcopyrite (Fig. 58). Within the sphalerite, small chalcopyrite grains ("chalcopyrite disease") form an approximate radial pattern.

These relationships indicate that the sulphide spots are probably cavity fillings, but their occurrence in what is apparently a welded tuff within the Hercules host rocks is problematical.

A particularly good exposure on 4 level shows a large pillow of spotty ore, about 1.5 m. across, surrounded by chlorite schist containing 1-2 cm. lenses of sphalerite, again with a zoned selvidge but here of chlorite and quartz.

Two credible alternatives are proposed for the origin of spotty ore . The first involves cavity- filling of vesicular tuff; the second involves dissolution of pre-existing carbonate nodules within the host rocks, and subsequent filling with ore minerals.



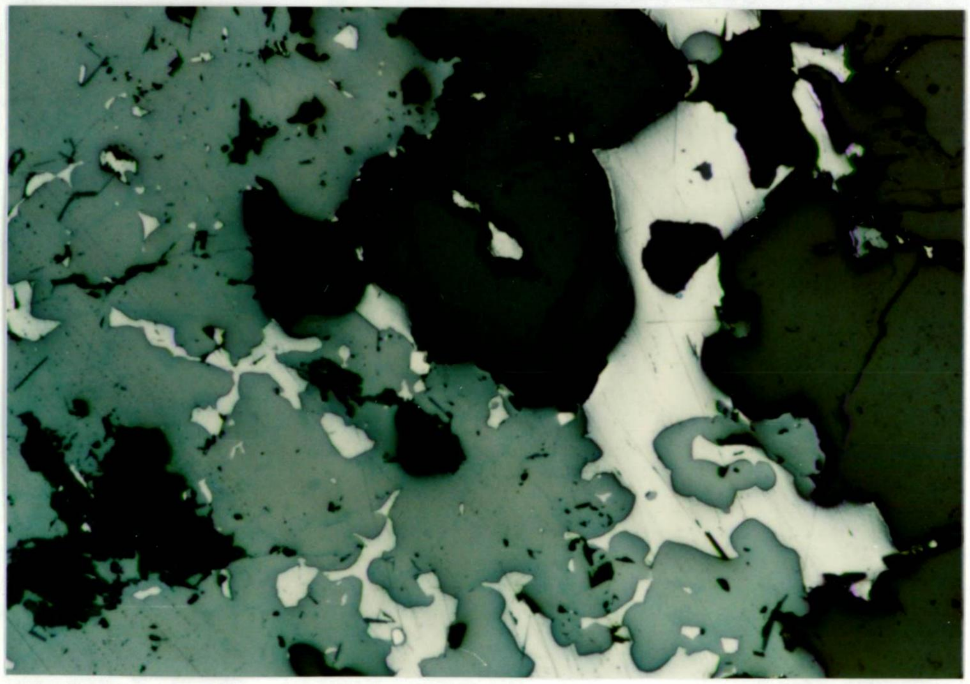


Fig. 56. Photomicrograph of porphyroblastic ore, Hercules, showing sphalerite, rimmed by galena, intergrown with quartz, TS 55606.
Above, PP light; below, reflected light.

1mm

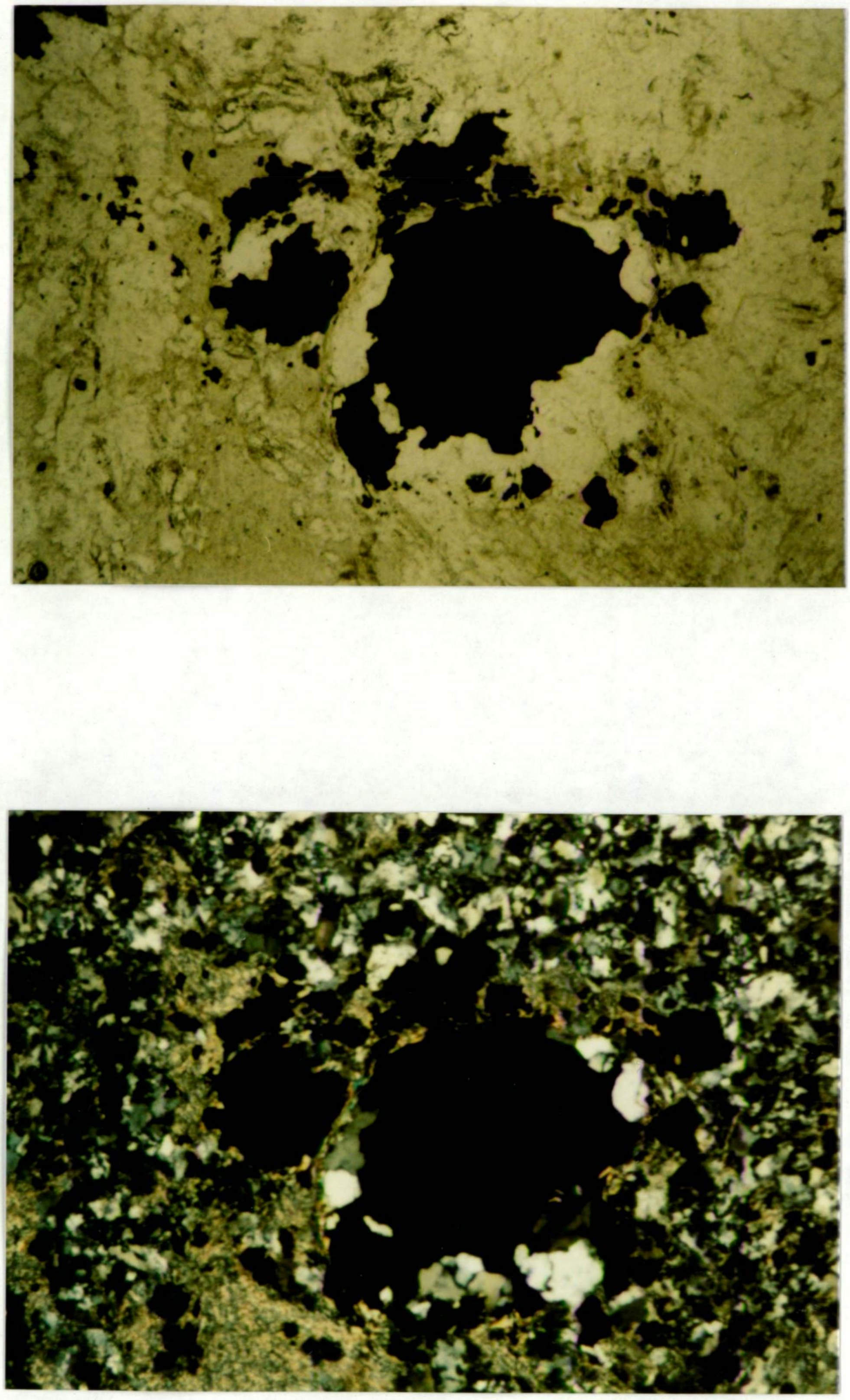


Fig. 57. Photomicrograph of "spotty ore", showing galena porphyroblast, rimmed by quartz and a thin sericite selvidge, in silicified tuff matrix, TS 47162. Above, PP light; below, XP light.

1mm

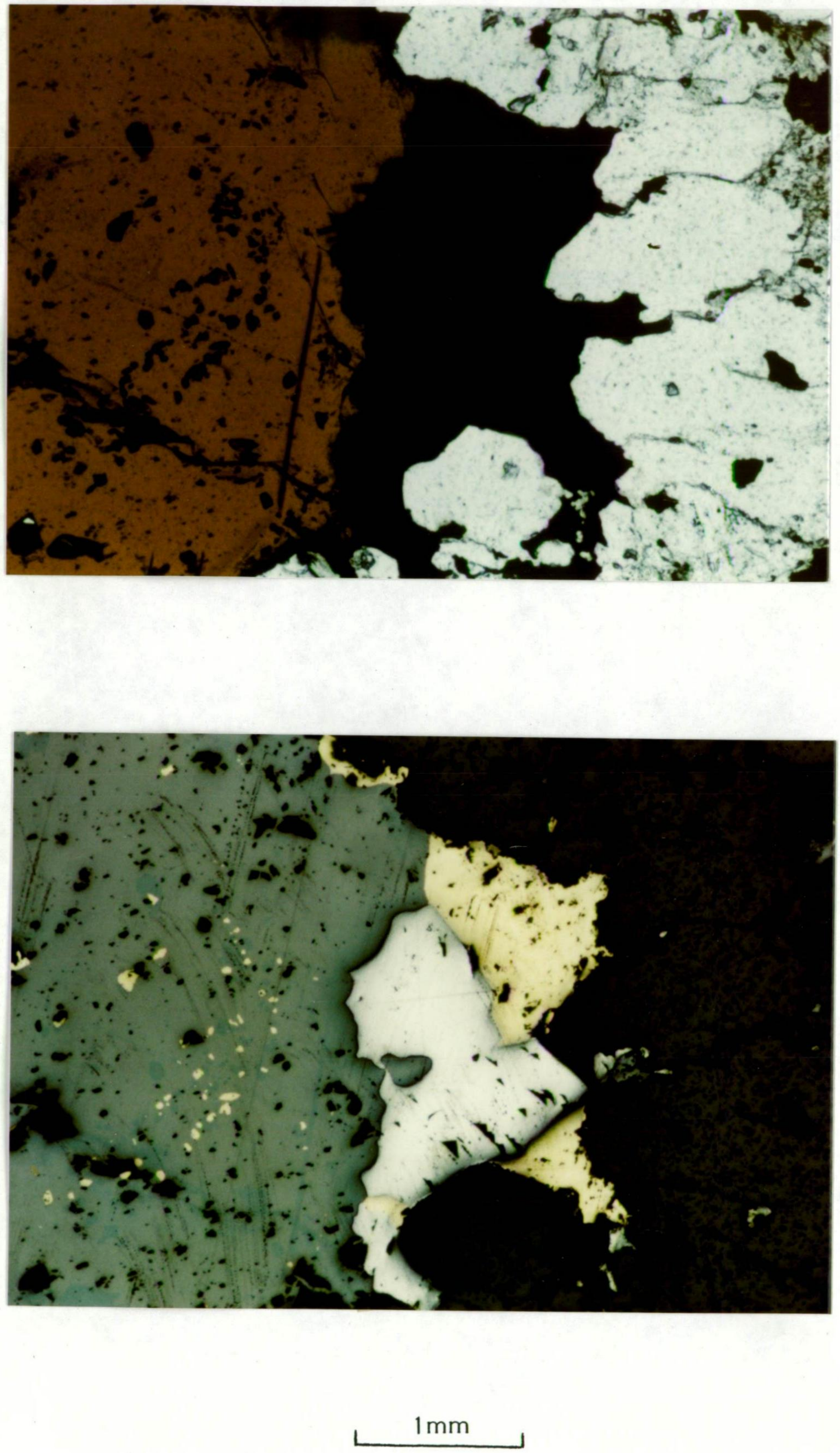


Fig. 58. Photomicrograph showing detail of sphalerite porphyroblast, rimmed by galena and quartz, TS 55301.
Above, PP light; below, reflected light.

Sericitic Ore

This consists of strongly cleaved sericite with ubiquitous pale brown sphalerite. It appears to be confined to the attenuated fold limbs and sheared margins of the ore lenses (eg. R lode) and is probably a modified form of another ore type, probably porphyroblastic ore. Lenses of pale yellow sphalerite, often rimmed by galena, are surrounded by sheaves of muscovite (Fig. 59).

Baritic Ore

Baritic ore is known only from G lens (which includes associated G 10 and a few smaller lenses). It varies from massive barite, to high grade banded galena- sphalerite- pyrite- barite, similar to that of H lens at Rosebery. Smaller barite lenses on both footwall and hangingwall side of the main G and G 10 lenses contain minor sulphides but often significant Ag (> 300 g/t) and Au (> 1.0 g/t) values.

Copper Ore

Down-plunge of nearly all the high grade ore lenses is copper-rich mineralization, which occurs in a number of forms ranging from massive pyrite to siliceous stringer pyrite-chalcopyrite.

Massive pyrite ore, of intergrown pyrite euhedra with minor disseminated and fracture-filling chalcopyrite, has a sparse chloritic matrix, and forms a keel beneath massive high grade ore in B- E lens. Stringer ore consists of pyrite- chalcopyrite stringers within a zone of disseminated pyrite. The stringers beneath the massive pyrite separate and thin, becoming progressively poorer in grade and pyrite content down-dip (see Fig. 55) and finally disappear close to the footwall contact.

6.4.6 Sulphur Isotopes

Sulphur isotope data for Hercules and South Hercules are presented in Table 2.

All results from the Hercules Pb-Zn lenses fall within the range of data for Rosebery, Green et. al. (1981), as does the only sample from the G lens barite lode. Pyrite nodules from the shales show values unlike the massive sulphide, and within a range typical of sedimentary sulphides.

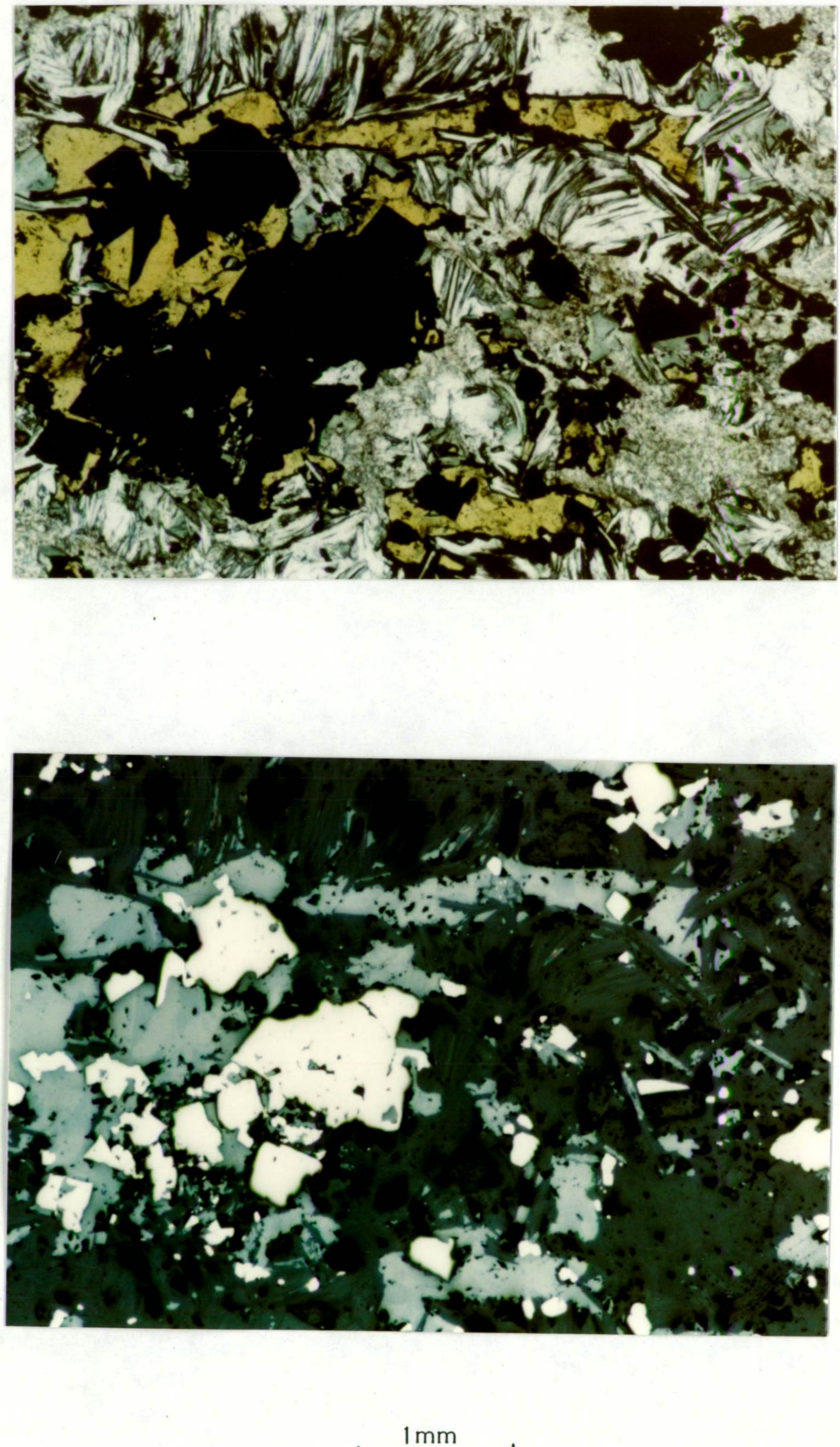


Fig. 59. Photomicrograph of R´ lode sericitic ore, showing pale sphalerite and porphyroblastic pyrite surrounded by sheaves of muscovite, in fine sericite schist matrix, TS RFW 7M7N.
Above, PP light; below, reflected light.

Table 2. Sulphur isotope data for Hercules and South Hercules.

Location	Mineral	Range $\partial^{34}S$	Average	No. Analyses
Pb- Zn lenses	py	11.2-13.2	12.1	6 (includes 4 analyses from Solomon et al., 1969)
	sp	10.9-15.6	12.5	3
	gn	10.3	10.3	1
G lens	py	12.7	12.7	2
	ba	40.7	40.7	1
Black slate	py	-3.8- +8.7	2.2	3 (includes 2 analyses from Solomon et al., 1969)
South Hercs.	py	12.7 - 13.6	13.2	4

6.4.7 Structure

The distribution of Hercules host rocks and overlying shales is controlled by a syncline - anticline fold pair best seen in exposures above the 4 level road. Folds are open to tight, with a strong axial plane cleavage varying between 60° and 75°E on a 340° to 010° strike.

Hall (1967) considered the ore lenses to have been localized within monoclinal and anticlinal structures, and that the ore bodies were emplaced in the cleavage.

Ore lenses are oriented parallel to the cleavage, and along with the enclosing of sheared, deformed host rocks, have been transposed into this cleavage, and in so doing can be seen to "intrude" host rocks and shales in places. The ore lenses are enclosed by sericite - chlorite schists, and within these by "oolitic" to massive carbonate, particularly on the hangingwall side, and strongly deformed (faulted and folded) host rocks, of which good examples are present in A lode and M lode.

Structures within these deformed zones include large rootless bulbs or lenses of "oolitic" carbonate rock, bound by thin sericitic shear zones, and pillows of siliceous spotty ore within chlorite schist containing similarly textured sulphides.

Faults and shear zones in the Hercules area have been discussed in Sect. 4.5.3.

6.4.8 Genesis

In considering the genesis of the Hercules orebody, some external constraints are imposed. Some ore types, ore grade and mineralogy, associated rock types, and the presence of an extensive footwall alteration zone, tend to place Hercules with other "normal" volcanogenic massive sulphide deposits. Unusual textures in several of the ore types such as "spotty ore" are best explained by either cavity-filling or replacement mechanism within existing tuffs.

Many of the complex features of Hercules may be explained by the transposition of at least one stratiform ore sheet into a number of ore lenses oriented within the cleavage (Fig. 60). A similar deformational history is proposed for the Caribou sulphide deposit, Canada, by Davis (1972). All the lenses at Hercules, with the exception of baritic G lens, are composed largely of porphyroblastic ore showing evidence of annealing, while G lens is the only one to consist of folded, laminated baritic galena - pyrite - sphalerite ore akin to the Rosebery barite lens. Analogy with Rosebery would suggest that G lens was originally a separate, stratigraphically higher, ore lens. The general zoning pattern for the lenses, from Pb - Zn down to massive pyrite then stringery chalcopyrite - pyrite at the base, is in agreement with the transposition of an original stratiform sulphide deposit.

Oolitic-textured carbonates, often recrystallized and showing botryoidal and cavity- filling textures, are closely associated with ore. They can be traced away from ore into relatively unaltered host rocks containing carbonatised feldspar in a felsic matrix, and are thus an alteration feature related to ore deposition. Similar carbonates occur at Rosebery.

6.5 SOUTH HERCULES

6.5.1 Stratigraphy

The stratigraphy at South Hercules is essentially the same as at Hercules, as it is an extension of the same mineralized horizon (Plans 3 & 4).

Feldspar- phyric tuffs, with occasional pumice and rare quartz crystals, overlie about 20 metres of east- dipping shale- siltstone, with minor sandstone and lithic- wacke beds, which mark the top of the poorly defined Hercules 'host rocks'. The host rocks consist of 45 to 50 metres of medium- grained, feldspar-phyric tuffs, composed of feldspar crystals and felsic lithics in an ashy matrix. Variable carbonate alteration, with close spatial relationship to mineralization, and intensity in proportion to the amount of mineralization, has resulted in a variety of carbonate morphologies overprinting the original textures.

Strongly silicified pumiceous tuffs, usually augen- textured but retaining original pumice and discernable silicified lithics in places, is present immediately below the host rocks, and is underlain by progressively less altered feldspar- phyric tuffs of the footwall pyroclastics. The difference between poorly bedded ashy tuffs and pumice-bearing altered footwall pyroclastics is ambiguous in many places due to the intensive alteration of all rocks near mineralization.

The sequence can be traced south from Hercules onto White Spur, where it is truncated by

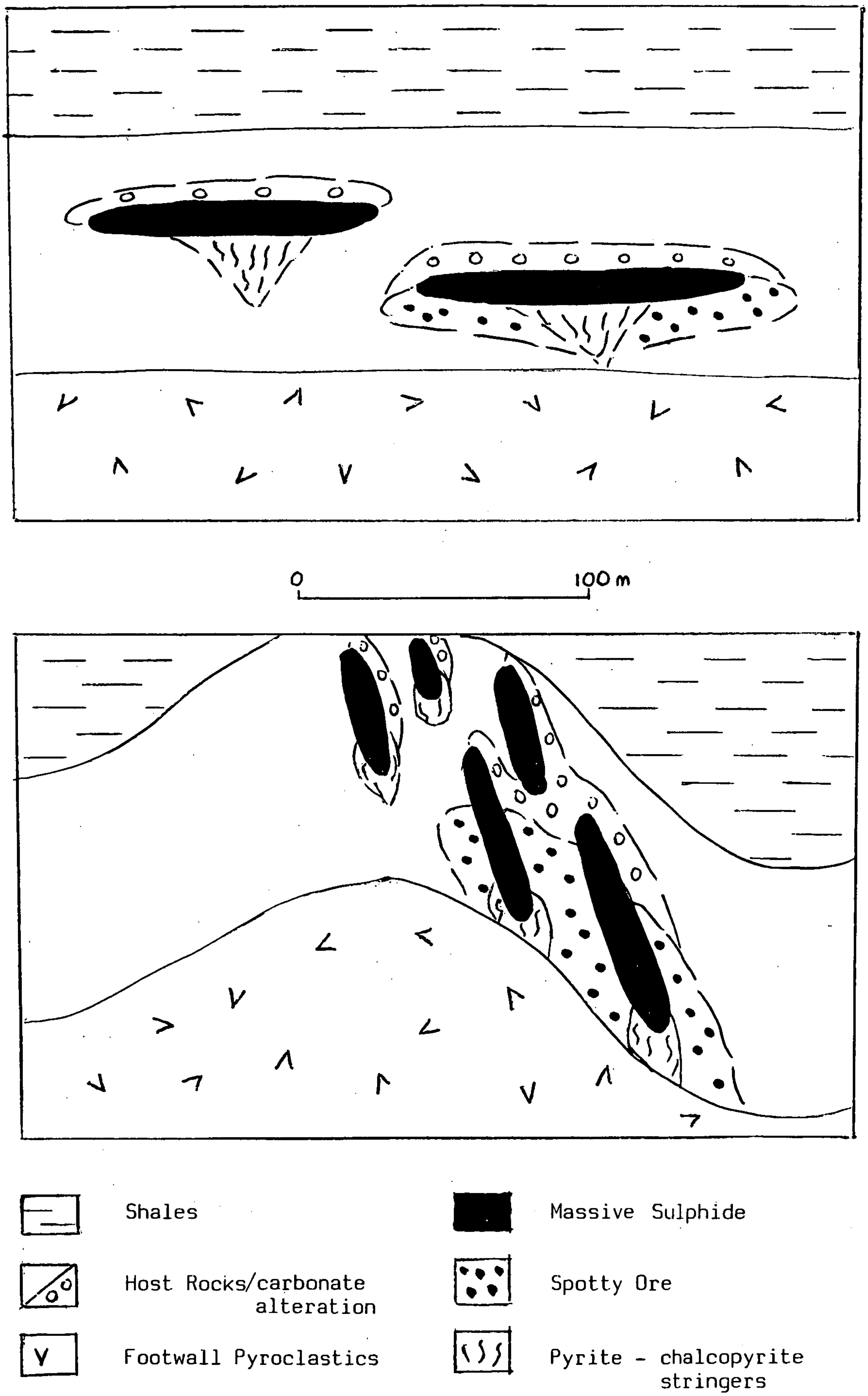


Fig. 60. - Cartoon diagram showing deformation of originally stratabound ore lenses at Hercules.

the unconformably overlying White Spur formation. Old pits and one shaft (Dunne's shaft) with one adit into the hill underneath, mark the mineralized horizon.

6.5.2 Mineralization

Mineralization in the Dunne's shaft area is of precious-metal mineralization and adjacent base metal mineralization. The deposit appears to be vertically zoned, with base- metal mineralization at the base, overlain by overlapping gold- and silver-rich disseminated sulphide ore, interspersed with pods to several metres diameter of variously textured carbonates.

The base-metal mineralization consists of 'pods' to 1-2 m diameter, similar to those seen in 'A' and 'M' lodes, of porphyroblastic sulphides in a silicified tuff matrix, which are bound by thin schist zones. Gold is present in the base-metal mineralization at levels of between 0.2 and 2.0 g/t. The base-metal zones usually thin and disappear down-dip.

Precious metal mineralization and carbonate pods are in most cases mutually exclusive, and represent two ?cogenetic alteration styles of the original tuff. The precious metal mineralization overlies the base- metal mineralization, and consists of quartz-sulphide veins and disseminated "spotty" ore similar to that at Hercules, in silicified tuff. Gold is usually in the range 3.0 to 6.0 g/t but in places up to 60g/t, while silver ranges from 50 to several hundred g/t. Acompanying the gold and silver is 2 to 5 % combined Pb and Zn. Extremely high Ag values (1,000 - 2,000 g/t) are confined to a thin interval at the very top of the mineralization, often overlapping with the high Au but in some cases adjacent to it and definitely above.

Carbonate pods are "oolitic"- or "pisolitic"- textured to massive, with cavity- filling and botryoidal textures, and their thickness and intensity is proportional to the intensity of adjacent mineralization, thus the carbonates are a good guide to ore. This carbonate alteration phase can be traced away from mineralization into felsic tuffs with carbonatised feldspar in the same stratigraphic position, in only tens of metres.

Siltstone in the hangingwall contains disseminated pyrite and arsenopyrite, and some zones of massive pyrite near the base. Gold may be associated with pyrite or arsenopyrite.

Bottrill (pers. comm.) observed jamesonite and sphalerite, with minor tetrahedrite, pyrite, arsenopyrite and chalcopyrite and rare gold, in polished thin-section (H1106, 28.5m.) from a silver-rich intersection, and suggested several stages of replacement of primary sphalerite and pyrite, by arsenopyrite, then tetrahedrite and jamesonite. Fander (1973) reports tetrahedrite, pyrargyrite and pearceite- polybasite from a different locality at South Hercules.

Sulphur isotopes from the South Hercules area (Table 3) fall in a small range of 12.7 to 13.6 for pyrite. This is marginally higher than the range of values for pyrite at Hercules.

Relationships between carbonates and mineralization, mineralization styles, and the suggested paragenetic sequence, all indicate that the precious metal zone at South Hercules was formed mainly by replacement and cavity-filling mechanisms.

6.6 DALMENY

At Dalmeny (Plan 2), mineralization was located by early prospectors in the Stitt River valley south of Rosebery, and early drilling (pre-1915) intersected 16 feet of ore, of which 3 feet assayed 31% Pb, 17% Zn, 15 oz. (466 g/t) Ag, and 1.18 g/t Au in the No. 2 bore. The high-grade intersection appears to be a small pod, probably related to a stockwork of galena-sphalerite veins in silicified tuff or lava of limited extent from the Stitt River (TS 55155). The high lead/zinc ratio of this mineralization is much higher than those normally present at Rosebery.

Subsequent drilling (DP 1, 2, 3, 4, and DP 85) intersected interbedded shales, sandstones and reworked tuffs, often carbonated and with disseminated pyrite or pyrrhotite, which are similar to the Rosebery host rocks, although grainsize is generally coarser, and there is less alteration at Dalmeny.

The east- dipping sediment sequence, and coincident I.P. anomaly, was drilled by DP 259, which intersected 0.20m of semi - massive sphalerite - pyrite in a sedimentary sequence very similar to that of Rosebery. A carbonate - altered porphyry occurs immediately below the sulphide, and this is followed in the drill hole by 20 metres of strongly altered phologopite - tourmaline plus silica, magnetite, fluorite assemblage.

6.7 KOONYA

A thin zone of strongly sericitic schist with asociated gossan outcrop adjacent to the Mt. Read Road on Bald Hill (Plan 2). Shale, sandstone and shaley sediment with coarse accidental lithics are present within a pumiceous, feldspar-phyric tuff sequence. A quartz-bearing unit, possibly a lava or intrusive outcrops adjacent to the mineralization, and is in places chloritized and pyritized (TS 54887, 54911).

A well-developed "quartz schist" alteration zone is exposed some distance east of the surface expression of Koonya mineralization, and is in fact more probably related to the Rosebery Lodes mineralization further east.

Zinc and lead as stringer and vein mineralization was intersected immediately below the gossan within pyritic, chloritized tuff, while some of the deeper drilling intersected mainly copper (up to 1 % over several metres) associated with disseminated to semi-massive pyrite with stringers chalcopyrite.

A distinctive suite of unusual, altered rocks appears to be spatially and genetically related to the mineralization, and occur in several of the Koonya drillholes. Rocks with recrystallized quartz nodules or spherulites, with abundant fluid inclusions, in a variably sericitized felsic matrix (TS KP 196 411ft., KP 197 177ft., 357ft., 412ft.) seem to be related to a similar rock (TS KP 198 283 ft.) with probable chloritized mafics, and quartz-chlorite amygdales (with fluid inclusions) in a sericitized felsic matrix, that is interpreted as an andesitic to dacitic lava. The surrounding tuffs are commonly altered, and have quartz-replaced lithics and quartz-pseudomorphed feldspar with chlorite pressure shadows, and chlorite veining with pyrite and sometimes sphalerite (TS KP 196 206 ft., KP 197 191 ft., KP 198 299 ft). The quartz is again full of fluid inclusions.

The stratigraphic position of the Koonya prospect is definitely within the footwall pyroclastics, beneath the Rosebery Lodes stratiform suphides and their associated footwall alteration zone. Mineralization is of stringer and vein style, both copper-rich and zinc-rich types are present and associated with chloritization, zones of disseminated pyrite, and unusual silicification hosting abundant fluid inclusions.

6.8 JUPITER

At Jupiter, a strong "quartz schist" alteration zone extends southeastwards from the Jupiter Pb- Zn workings (Plans 2 & 3). The No. 1 and No. 2 adits were driven into the "quartz schist" chasing massive pyrite- chalcopyrite mineralization.

Pelitic ash with minor pyrite outcrops east of the No. 1 adit and extends northwards, with massive, quartz - phyric intrusive abutting these sediments further east and continuing into feldspar- phyric tuffs of the footwall pyroclastics.

The Jupiter Pb - Zn workings are located within the broad "quartz - schist" alteration zone, and are confined to a 0.3 to 1 metre wide strongly cleaved sericite schist. Pyritic banded chert (or strongly silicified tuff) is present to the west on the Williamsford Road, while the alteration hosting the pyrite - chalcopyrite mineralization lies to the south-east.

The Natone Volcanics and Stitt Quartzite wedge out just north of Jupiter where truncated by the Rosebery Fault. The fault dips at 40° E underneath the volcanics, and limits the potential for any improvement of the Jupiter Pb - Zn horizon at depth or along strike. Several subsidiary parallel and divergent faults, have caused local anomalous dips as fault blocks have been rotated close to the Rosebery Fault.

Massive pyrite with minor chalcopyrite at the Jupiter Cu workings is apparently not stratiform, and fades rapidly along strike into stringer, then disseminated pyrite mineralization. Chlorite often occurs as the matrix to semi-massive pyrite, and is still present associated with disseminated pyrite in the surrounding siliceous alteration zone.

The Pb - Zn mineralization consists of several types; disseminated sphalerite in sericite schist outcrops near the Jupiter bend, massive poorly banded galena- pyrite- sphalerite can be found on some dumps and was intersected in old drillholes. Assays show it to be very narrow (0.3-0.5 m.) but high grade (approx. 25% Zn, 5% Pb, 0.4% Cu, and up to 500 g/t Ag and 4.0 g/t Au) with surrounding, disseminated mineralization having proportionally lower grades. Rhodochrosite is recorded as accompanying the mineralization in one place, and minor barite is also present and is consistent with the correlation of the Jupiter Pb - Zn horizon with the Ring P. A. horizon.

6.9 RING P.A.

The Ring P.A. workings (also called North Hercules) followed a 10 cm. band of sphalerite - pyrite - galena - barite which is exposed on the Williamsford - Hercules Road (Plan 3) (Figs. 61, 62). This is contained within fine grained shard-bearing ashy tuffs (TS 55748, 55749) that extend from just below the mineralization to some 100 m stratigraphically above it. The mineralization is significant in that it occurs several hundred metres stratigraphically below the Hercules mineralization. A 3m chip sample across the mineralized horizon and adjacent tuffs assayed 0.3% Pb, 2.4% Zn, 0.17% Cu, 13 g/t Ag, and 0.09 g/t Au.

The mineralization is apparently stratiform as it dips east at about 60°, compared with cleavage at 80°E, and is composed of layered sphalerite - galena - barite, and is not the usual vein remobilisation assemblage of quartz - carbonate - sulphide. A small breccia occurs immediately below the sulphide horizon. The occurrence of stratiform Pb - Zn mineralization in the footwall may also explain the occurrence of a rounded, elongate "clast" some 15 cm long, of massive sulphide in the Hercules footwall (7 level drive, 1100'N, 300'W H.G.).

Drill holes NHP 194, NHP 195 targeted but did not intersect the Pb - Zn horizon although they passed from fine - grained, ashy felsic tuffs into altered, pumiceous tuffs in the footwall of the mineralized horizon. Drill hole H 955 tested the North Hercules area at depth, and intersected a one metre wide weakly altered zone within pumiceous tuffs.

6.10 EAST HERCULES

A series of pits and trenches, and one shaft, marks a linear zone of disseminated pyrite mineralization at East Hercules (Plan 3). The best mineralization, below a small gossan, was intersected in the shaft and a drillhole from underground at Hercules (drillhole H 391), and consists of chlorite schist with thin bands and stringers of pyrite - chalcopyrite, in a pyritic,

Fig. 61. Ring. P. A. sulphide horizon, Haulage Road near Hercules.

Fig. 62. Detail of Ring P. A. sulphide horizon. Note sulphides enclosing sericite schist fragment. Haulage Road, near Hercules.

chlorite-silica altered zone. The alteration with associated pyrite - chalcopyrite vein mineralization, and surrounding disseminated pyrite zone, appear to occur within a quartz - porphyry body, which is in turn surrounded by a zone of silicification.

The relationship of mineralization with intrusive quartz - porphyry would indicate the mineralization is probably a result of post - emplacement hydrothermal activity, generated by the intrusion.

6.11 DALLWITZ

A series of six drillholes at Dallwitz (Plan 3) were targetted at a combination of Turair (airborne E.M.) and soil geochemistry anomalies, together with the presence of thin-bedded shale- siltstone, which was at the time considered to be equivalent to Rosebery host rocks.

Current interpretation of the geology indicates that the Dallwitz sediments are stratigraphically higher than the potentially mineralized host rock horizon, although erosion prior to deposition of the Dallwitz sediments appears to have led to their deposition transgressively across the footwall pyroclastics, host rocks, and quartz - phyric epiclastics of the Hercules sequence.

Mineralization intersected consists of two types, minor pyrite and pyrrhotite as blebs and disseminations in siltstone, and carbonate veins carrying a little sphalerite, galena and pyrite. It is the latter style that is responsible for the values obtained in split core, as listed below, nevertheless mineralization is largely confined to the fine - grained sediments and is accompanied by weak, local chloritization and silicification.

The mineralization within the veins is attributed to remobilisation of a minor sulphide component in the sediment sequence during metamorphism. Metal values from split core in mineralized intervals are in the ranges 0.1 - 0.5 % Pb, 0.2 - 2.5 % Zn, 0.01 - 0.06 % Cu, up to 9 g/t Ag, and less than detection of 0.1 g/t Au.

6.12 QUARTZ- TOURMALINE VEIN MINERALIZATION

Quartz tourmaline veins and veinlets are abundant over an area of several square kilometres, centred just south of Rosebery. The major vein, the quartz -tourmaline filled Rosebery Fault, is only mineralized where it contains the quartz-tourmaline assemblage between Rosebery and Jupiter. A smaller vein runs parallel from Rosebery to Bald Hill, and quartz-tourmaline veinlets are pervasive in the Williamsford Road - Rosebery footwall - South

Rosebery area. The structural control on this type of mineralization is obvious.

The mineralization was exploited around the turn of the century at the Salisbury and Chamberlain mines on the Rosebery Fault, and Mt. Black Pty mine at South Rosebery. Minor minerals recorded in the quartz- tourmaline vein are pyrite, chalcopyrite, arsenopyrite, bismuthinite, and wolframite (Smith, 1898; Waller, 1902). Even at that time the deposits were regarded as separate from the base- metal mineralization, being true "fissure veins".

The Rosebery Fault has been sampled along its known mineralized length from drillcore and surface exposures. Gold is consistently in the order of 1.0 g/t and up to 7.0 g/t, Cu is consistently elevated, in the order of 0.1%, and up to 0.45% at Salisbury, while Pb, Zn and Ag are low in the vein itself, usually less than 0.1% for Pb and Zn and up to 10 ppm. for Ag. A section through the mineralization in drillhole CP 281, showed the vein to be anomalous in Au (0.97ppm), Cu (0.2%), As (1.15%), Sn (0.12%), and B (260 ppm). W, although not analysed, is problaby present and has been reported from this type of mineralization at South Rosebery (the Mt. Black Pty. mine). U and Th appear to be depleted (U< 5ppm and Th < 5ppm) in the vein, when compared to averages of 10 ppm and 20 ppm respectively, in surrounding rocks. Analyses of the quartz-tourmaline mineralization are listed in Table 3.

Table 3. Analyses of the quartz-tourmaline mineralization.

Sample		Pb ppm	Zn ppm	Cu ppm	Ag ppm	Au ppm	Sn ppm	Bi ppm
BP 97	233 - 236 ft	120	295	1450	1.0	0.40	6	
	236 - 240 ft	295	520	825	3.0	0.18	64	
	240 - 250 ft	150	170	3800	4.5	1.47	140	
	250 - 255 ft	35	225	40	<0.5	0.14	52	
CP 281	165.0-167.9	10	40	170	<0.5	0.07	31	
	167.9-169.8	905	730	2150	10.0	0.97	1270	260
	169.8-171.0	4.15%	95	85	172	0.01	19	<5
	171.0-173.0	1.96%	130	35	86	<0.01	6	<5
	173.0-175.0	0.30%	45	5	12	<0.01	<3	<5
47185		145	70	855	4.0	0.69		
47186		105	140	120	1.0	0.21		
47189		125	15	210	2.5	0.77		
47192		15	35	235	3.0	6.77		
55613						0.14		
55616						2.92		

The BP 97 samples are all of vein material, those of CP 281 are of a section across the vein, the first sample being above, the second the vein itself, and the remaining three below.

6.13 MINERALIZATION IN DUNDAS GROUP ROCKS

The only mineralization known in Dundas Group rocks are quartz veins carrying galena in places. These outcrop on White Spur (at 5364710N, 375560E), in the White Spur Creek (5367770N, 375480E), and along a fault south of Conliffe Creek. Pits are present on all these outcrops, and shows the interest taken in them by the early prospectors. Stoped narrow quartz veins south of Williamsford, called Hamilton's Workings, were probably auriferous. Assays of vein material from the quartz-galena veins are listed in Table 4.

Table 4. Assays of vein material from the quartz- galena veins.

S/N	%Pb	%Zn	ppm Ag	ppm Au
55778	13.0	1.3	220	0.025
56085	7.4	0.2	46.5	<0.008
56339	14.4	7.2	475	0.008

Metal ratios of these veins are quite different from other styles of mineralization, in having Pb>>Zn, and high Ag with no corresponding Au.

7 RELATION BETWEEN STRATIGRAPHY, STRUCTURE AND MINERALIZATION

7.1 RELATION BETWEEN STRATIGRAPHY AND MINERALIZATION

At least two mineralised horizons are present in the area, accounting for known occurrences of stratiform and stratabound sulphides.

7.1.1 Ring P. A. - Jupiter Horizon

Within the footwall pyroclastics, a thin, discontinuous mineralized horizon extends from the Ring P. A. prospect to the Jupiter prospect. At Jupiter, an altered zone of "quartz schist" marks an area of a significant amount of hydrothermal discharge onto the sea floor, with a small and thin Pb-Zn lode and an overlying(?) pyrite- chalcopyrite stringer zone.

Between Jupiter and Ring P. A., a thin barite bed, containing virtually no sulphides, is present in at least one locality at approximately the same stratigraphic level, but is associated with extremely weak alteration and is interpreted as a low-temperature, distal equivalent of the mineralization.

At Ring P. A., a thin bed of Pb-Zn-barite mineralization, hosted by vitric tuffs, is underlain by a small, vent- like breccia zone (Fig. 61), overlying a zone of moderately altered pumiceous tuffs.

The thin, sporadic mineralization appears to lie at a specific stratigraphic level, some several hundred metres in the footwall of the Hercules orebody.

7.1.2 Rosebery - Hercules

It is well established that the Rosebery ore deposit is a stratiform, syngenetic sulphide deposit (Brathwaite, 1969; Green, 1983), so it is logical that repetitions of the sequence may contain similar deposits. Rosebery Lodes was extensively drilled when discovered for this reason, but contained little in the way of economic sulphides. Nevertheless, it showed the potential host stratigraphy continued southwards.

Although detailed mapping has not resolved whether Rosebery and Hercules are at the same stratigraphic level, the parallel sequences, would suggest that the mineralization formed by a similar process and probably at a similar time at both localities.

The Hercules deposit, now a number of lenses transposed into the cleavage, was originally at least one stratiform, sheet - like body, perhaps with a separate, stratigraphically higher barite lens (G lens) as at Rosebery. At South Hercules, precious metal mineralization is grossly stratabound, but many features indicating a replacement origin are present.

7.1.3 Koonya

Mineralization at Koonya is of both galena - sphalerite and pyrite- chalcopyrite stringer styles, some distance into the footwall of the Rosebery Lodes stratiform mineralization. Pyritic chlorite alteration appears to be associated with an amygdaloidal lava or intrusive. No stratiform mineralization is present in any of the drillholes in the area.

As the Koonya mineralization is in the footwall of known, minor stratiform mineralization at Rosebery Lodes, it is possible that Koonya represents subsurface deposition from hydrothermal solutions *en route* to their exhalation on the sea floor.

7.1.4 Dalmeny

Lead- zinc mineralization at Dalmeny occurs within a sedimentary sequence, adjacent to a thin carbonatized porphyry and an underlying zone of tourmaline - phlogopite - magnetite alteration, and close to a structurally overlying zone of silicification. It has affinities with stratiform mineralization, in its location in the sediments, metal ratios, and associated alteration. The close association with porphyry, and stringer - style sulphides, indicate a epigenetic origin.

7.2 CALDERA COLLAPSE MODEL

The geological changes which occur at the footwall pyroclastic / host rock contact (discussed in Sect. 5.1), suggest a major volcanological event at that point. With this in mind, the association between mineralization and the evolution of calderas has been reviewed in order to identify analogous situations.

7.2.1 Mineralization in Subaerial Calderas

Smith and Bailey (1968), in their classic paper on resurgent cauldrons, relate mineralization to late stage solfatara and hot-spring activity, well after caldera collapse and resurgence. McKee (1979) also regards the minor mineralization associated with ash flow sheets and calderas in Nevada as accompanying late - stage, post - resurgent igneous activity.

In Central Peru, Noble and McKee (1982) describe vein - style silver- rich mineralization with associated hydrothermal alteration, which took place relatively shortly after caldera collapse. Steven et al. (1974), in a paper on the relation between mineralization and calderas in the San Juan volcanic field, again note the association of post - subsidence intrusive and extrusive igneous activity with mineralization.

A quote from Steven et al. (op. cit.) summarizes the relation between mineralization and subaerial calderas: "nothing in the process of ash- flow eruption or caldera subsidence leads inherently to hydrothermal activity and mineralization. Eruption and subsidence, rather, create favourable plumbing systems in areas of active magmatism." Clearly, in subaerial calderas, the mineralization is reliant on igneous activity to provide energy for any hydrothermal cell, and possibly a component of the hydrothermal fluids and their contained metals.

7.2.2 Mineralization Associated with Submarine Calderas

Japanese workers on the Kuroko deposits were instrumental in relating stratiform, volcanogenic mineralization in the Kuroko deposits to synchronous submarine caldera structures.

Ohmoto (1978) developed the caldera model to explain the common occurrence of rapid subsidence structures, the development of large- scale seawater circulation systems, and high heat flow that accompany the formation of volcanogenic sulphides at the sea floor. He also states "If the creation of a submarine caldera was the only requirement necessary for establishing an ore- forming seawater circulation system, one might also expect mineralization to be associated with the first caldera - forming episode (i.e. caldera collapse)...". Ohmoto (op. cit.) cites the Rosebery - Mt. Lyell district as one where submarine calderas appear to have been important.

Kouda and Koide (1978) relate ore deposits in the Odate area of Japan to a resurgent submarine cauldron, but the timing of mineralization here is not immediately after caldera collapse, as some dacitic material was deposited between collapse and mineralization. Harley (1979) related various styles of mineralization in the Bathurst - Newcastle mining district of Canada to various stages in the evolution of a caldera; in particular the stratiform sulphides were formed during or shortly after the main caldera- forming eruptions. Sillitoe (1982) recognised that rhyolite - hosted massive sulphide deposits are confined to habitats of extensional tectonics, and in this regime clusters of massive sulphide deposits are often emplaced immediately following voluminous pyroclastic eruption and caldera collapse. Ohmoto and Takahashi (1983) further developed the caldera model for Kuroko deposits.

7.2.3 Caldera model for Rosebery - Hercules area

From the examples above, it can be seen that mineralization often occurs either immediately or a short time after caldera collapse. In subaerial calderas, mineralization is vein-style, while stratiform base metals may be deposited in submarine calderas.

Sparks and Huang (1980) report the Minoan eruption of Santorini (Greece) to have been followed by caldera collapse to a depth of some 600 - 800 metres, which would certainly be enough to convert a terrestrial environment to a marine one with sufficient depth to prevent boiling of hydrothermal fluids.

Green (1983) proposed a caldera environment for Rosebery, and futher evidence is presented here, based on data from chapters 3, 5 and 6. The following sequence of events, summarised from geological interpretations of the Rosebery - Hercules area, and by comparison with mineralization related to caldera formation elsewhere, is proposed:

1. Deposition of caldera- forming ash-flow tuffs (footwall pyroclastics),
2. Rapid subsidence as the caldera collapses,
3. Ore formation, due to activation of hydrothermal circulation systems along collapse structures,
4. Deposition of quartz- phyric tuffs and epiclastics, with some intrusive and extrusive activity,
5. Resurgence, and
6. Next cycle of eruption to build up the Mount Black Volcanics.

Scant evidence for resurgence is in the change in strike along the belt of footwall pyroclastics, together with the noticeable arcuate shape of their upper contact as exposed between Rosebery and South Hercules, and rapid thickening of the quartz phyric tuffs north of Rosebery and away from the centre of resurgent doming.

There are only a few clues to the size and shape of the supposed caldera, mainly because the surface provides a section through the volcanic sequences. The known extent of footwall pyroclastics along with their possible doming, from Rosebery to South Hercules, a distance of 12 km., may be an approximation to one dimension of the caldera.

8 ALTERATION

8.1 INTRODUCTION

Alteration of volcanic rocks commences as soon as they are deposited, through processes of devitrification and recrystallization. Hydrothermal alteration related to mineralization occurs in the vicinity of the Rosebery and Hercules orebodies, and at several smaller prospects.

Metasomatic alteration, presumeably related to a large granitic intrusion, affects a considerable area near Rosebery, including the southern end of the Rosebery orebody. An extensive zone of silicification, on the footwall side of the Rosebery Fault, may also be related to granitic intrusion. Local areas of various, minor alteration styles, such as albitization, chloritization, and epidotization, are discussed briefly.

8.2 ALTERATION PROCESSES IN ASH FLOW TUFFS

As soon as a pyroclastic flow is deposited, vapor-phase crystallization and devitrification of glassy areas, begin to alter the original mineralogy, texture and chemistry of the rock. These processes and products are described in detail in Ross and Smith (1961) and Lambert (1974).

Ross and Smith (1961) distinguish the two processes on the basis that devitrification forms crystals within the groundmass or glass shards, while vapor - phase crystallization takes place within open spaces.

Products of devitrification are predominantly crystobalite and feldspar, while those of vapor - phase crystallization are tridymite, alkali feldspar and crystobalite (Ross and Smith, 1961)

Spherulites and lithophysae occur in some welded tuffs, and are locally abundant (Ross and Smith, 1961), although Wright and Coward (1977) state that the presence of nodules, representing original gas vesicles filled with quartz, may be a good indication that the flow has been in contact with water. Lithophysae are abundant in a small, well exposed area south of Hercules (Fig. 18), within a massive to bedded, pelitic ash closely associated with a coarsely pumiceous rock, interpreted as an ignimbrite (see Sect. 3.5.5).

8.3 HYDROTHERMAL ALTERATION

Significant areas of footwall pyroclastics have been strongly altered to quartz - sericite± chlorite schists in the vicinity of stratiform mineralization at Rosebery, Hercules, Rosebery Lodes, Jupiter and Ring P. A. The distribution of altered zones is shown in Plan 5. The alteration zone at Rosebery has been described in detail by Green (1983) and Naschwitz (1985).

Eastoe (1980, 1981) worked on alteration zones in the Mt. Read Volcanics, but attempted to use the altered zones as showing the position of a single, stratigraphically controlled mineralization episode.

Allen (1986) describes pseudo- ignimbrite textures resulting from devitrification and hydrothermal alteration processes affecting flow - banded, massive or hyaloclastite rhyolite lavas, from the Cowombat Rift in the Benambra area. At both Rosebery and Hercules, however, gradations from strongly altered footwall chlorite - quartz - sericite schists to the surrounding tuffs, which contain well- preserved tuff textures such as pumice, fiamme and shards, can be seen in several sections.

Alteration Index

The alteration index was defined by Ishikawa et al. (1976) as 100 times the ratio of MgO + K_2O, divided by Na_2O + CaO + MgO + K_2O, to reflect the degree of hydrothermal alteration related to massive sulphide deposits by comparing "enriched" to "depleted" elements within a range up to one hundred. The alteration index was developed for the Japanese Kuroko deposits, which have considerable enrichment of MgO (as chlorite). This is not the case for Rosebery and Hercules, where the index is considered less effective.

Relatively unaltered rhyolitic volcanics from the Rosebery area (average of 35 samples, Table 5) have an alteration index of 52, compared to 68 for the Rosebery alteration zone (23 samples), 95 for Hercules (4 samples), and 84 for the "massive siliceous rocks" (10 samples).

8.3.1 Rosebery

Altered footwall rocks occur extensively below the Rosebery orebody, and are most intensely altered immediately underlying host rocks containing the ore lenses. The intense alteration, termed "quartz schist" consists of siliceous augen, defined by sericite foliae. With decreasing alteration, smeared, sericitised and carbonatised feldspar appears and gradually becomes fresher; silicification decreases until the rock is dominantly felsic; and sericite foliae become recognisable as smeared pumice or fiamme. The alteration is characterised by low Na_2O values and low Na_2O/K_2O and Sr/Rb ratios (see below).

Chlorite is a common minor component of "quartz schist" alteration , occurring in a number of forms. Ultra- fine chlorite imparts a greenish hue to the rock, pumice fragments may be composed of chlorite along with sericite, and zones of sericite - chlorite schist are found, usually close to the host rock contact.

Variation in the degree of alteration is at least partly in response to variation in the original lithology. Mapping of the footwall shows some areas within the broad alteration zone with only slight smearing and carbonatisation of feldspar. Obviously original permeability, porosity and degree of fracturing will affect fluid flow through any particular unit.

Geochemistry

Naschwitz (1985) studied the geochemistry of the Rosebery ore deposit, particularly the alteration zone, in detail. He concluded that the hydrothermal alteration had enriched the pyroclastics in SiO_2, K_2O, Rb and S, and depleted them in Al_2O_3, Na_2O, TiO_2, CaO, Zr, Y and Nb.

Green (1983) in an earlier study, concluded that Al, Nb and Zn were neither enriched nor depleted; Mg, Mn, Rb, H_2O and Fe (non-sulphide) are generally enriched; and Na and Sr are strongly depleted.

The difference in results between the two authors can be attributed to several factors, mainly the number of samples, and treatment of data. Naschwitz (1985) used 23 samples of altered footwall rocks and applied various statistical techniques, while Green (1983) used 6 samples and compared them with other groups in both general terms and in terms of chemical components relative to supposedly immobile TiO_2.

Table 5. Major element chemistry of main rock groups in the Rosebery area. Data from Naschwitz (1985). Group A - unaltered rhyolitic volcanics (n = 35), Group B - "schists" (altered footwall rocks)(n = 23), Group C - "massive siliceous rocks" (n = 10). x = average, sd = standard deviation, n = number of samples.

Group		SiO2	TiO2	Al2O3	Fe2O3	MnO	MgO	CaO	Na2O3	K20	P2O5	S
A	x	79.90	0.38	14.25	2.42	0.06	0.59	0.33	3.06	3.12	0.05	0.01
	s.d	3.07	0.11	1.53	0.77	0.07	0.40	0.41	1.06	0.99	0.06	0.04
B	x	79.28	0.08	12.23	1.41	0.07	0.18	0.57	0.85	0.55	0.08	0.19
	s.d	3.20	0.04	1.88	0.56	0.11	0.18	0.57	0.85	0.55	0.08	0.19
C	x	74.66	0.27	13.07	3.31	0.17	0.87	2.20	0.31	4.53	0.03	0.29
	s.d	2.78	0.09	1.72	1.96	0.31	0.83	0.41	0.35	1.08	0.04	1.00

Sample No.	✓ 47173	✓ 47174	✓ 47175	◇ 55281	55285	† 55320	† 55349	55368	◇ 55457	✓ 55525
Al_2O_3	12.9	11.2	10.5	13.9	12.9	15.5	16.4	11.2	13.4	12.4
SiO_2	74.0	76.9	74.3	73.5	71.4	66.0	58.0	72.5	74.0	71.9
TiO_2	0.31	0.25	0.28	0.35	0.33	0.50	0.56	0.27	0.31	0.33
FeO	1.11	0.90	2.78	1.26	0.92	1.02	1.57	4.85	1.95	3.53
Fe_2O_3	0.65	2.00	2.85	1.15	1.00	1.75	0.50	1.65	0.70	1.75
MnO	0.44	0.07	0.20	0.05	0.10	0.27	0.17	0.19	0.18	0.27
CaO	0.74	0.02	0.01	0.28	2.85	1.45	4.80	0.01	0.35	0.05
K_2O	4.30	4.00	3.05	2.40	3.60	4.00	3.80	2.85	3.25	3.55
MgO	1.40	0.65	1.20	0.85	1.25	3.00	5.40	1.70	0.55	1.70
Na_2O	0.09	0.05	0.05	3.74	0.67	0.22	0.49	0.05	3.37	0.06
P_2O_5	0.030	0.025	0.035	0.035	0.050	0.090	0.135	0.030	0.060	0.035
SO_3	0.30	2.20	3.10	0.030	0.030	2.60	0.090	0.60	0.050	0.65
CO_2	1.10	0.25	0.25	0.15	2.30	1.60	4.20	0.15	0.70	0.20
Hg0-	0.20	0.11	0.07	0.09	0.07	0.11	0.13	0.17	0.16	0.18
H_2Ot	2.15	2.40	2.80	1.65	2.10	3.55	3.85	3.00	1.25	3.00
Oxide Total	99.7	101.0	101.5	99.4	99.6	101.6	100.1	99.3	100.2	99.61
Zn	1000	160	960	55	1700	90	65	80	65	140
Pb	475	50	35	5	5	30	10	5	X	10
Cu	55	25	110	10	5	15	10	10	10	120
Rb(ppm)	230	220	160	120	170	190	180	140	140	210
Sr "	30	15	7	190	90	55	140	7	200	8
Ba "	1150	1500	810	670	1150	4250	2400	580	840	940
Na_2O/K_2O	.021	.0125	.016	1.56	0.186	0.055	0.129	0.0175	1.037	0.017
Sr/Rb	0.13	0.07	0.04	1.58	0.53	0.30	0.78	0.05	1.43	0.04

Analysed by Analabs Pty. Ltd., Cooee ✓

TABLE 6 - Whole Rock Analyses of Rocks from the Hercules Area.

See Appendix 1 for sample identifications and locations.

✓ [illegible] wall

† host rocks

◇ [illegible] wall

8.3.2 Rosebery Lodes

A narrow zone of altered tuffs is present in the footwall of the Rosebery Lodes prospect. The width of alteration is a reflection of the paucity of mineralization in the area, but further south, a presumed extension of augen - textured quartz - sericite schist is surrounded by glacial cover just east of the Koonya workings. No major element analyses are available of this zone.

8.3.3 Hercules

A zone of distinctively altered pumiceous tuffs extends from South Hercules, through Hercules where they are well exposed in various mine workings, along Copper Ridge to the Ring P. A. prospect. Strong "quartz schist" alteration is confined to the immediate footwall of the ore lenses for a few tens of metres. The remaining alteration zone typically consists of green chlorite- sericite fiamme (usually 10 to 20 cm length, rarely to 1m), sometimes pyritized, in a finely crystalline silicified groundmass with minor disseminated pyrite and sphalerite. In less intensely altered areas, feldspar is present, becoming less smeared and sericitized away from mineralization.

Relatively fresh, unaltered footwall pyroclastics are present between Williamsford and Bakers Creek, and are usually crystal - lithic tuffs with coarse pumice or fiamme, and albitized feldspar crystals in a felsic groundmass.

Geochemistry

Ten samples of variously altered rocks from the Hercules area were analysed for major and some minor elements (Table 6). The purpose of the analyses was to quantify alteration characteristics.

The samples analysed comprise several geologically and geochemically distinct groups. Silicified and chloritized footwall pumiceous tuffs are represented by 47173, 47174, 47175 and 55525, which are characterised by strongly depleted Na_2O (0.05 to 0.09 %), low Al_2O_3, variable MnO and CaO, high H_2O (total) and MgO (0.65 to 1.70 %), and similar TiO_2 and K_2O, when compared to relatively unaltered feldspar - phyric fiamme - bearing tuffs from the hangingwall (S/N 55281) and Bakers Creek (S/N 55457).

Host rocks (S/N 55320, 55349) have relatively high Al_2O_3, TiO_2, CaO and MgO. Both SiO_2 and Na_2O are low, but the latter is not as depleted as the footwall rocks.

Chloritized and silicified pumiceous tuff from Mt. Hamilton, in the hangingwall, show this altered zone to have low Na_2O but unusually high FeO.

Sheared, sericitised and carbonatised tuffs near the Mt. Hamilton fault at the northern end of the host rocks (S/N 55285) have a chemistry showing moderate alteration. High CaO and CO_2 are an indication of the carbonatization of feldspar, and Na_2O is depleted.

Table 7 shows whole rock analyses for footwall, host rocks and hangingwall, compiled from data presented in Table 6, and from Fitzgerald (1974). The three groups are chemically distinct, and have several characteristics that distinguish each from the others, as outlined below.

Footwall   Low Na_2O, high SiO_2, and low Na_2O/K_2O and Sr/Rb ratios.

Host rocks   High MnO + CaO + MgO, alao CO_2 and BaO; low SiO_2.

Unaltered hangingwall   High Na_2O and Na_2O/K_2O, Sr/Rb ratios.

8.3.4 East Hercules

An alteration zone at East Hercules, similar in hand specimen to the footwall alteration, is spatially related to an intrusive rhyolite. Thin stringer - style pyrite and chalcopyrite, and surrounding disseminated pyrite in chlorite schist, occurs within the strongest alteration. One sample from this zone, from Mt. Hamilton, is included in the analysis of alteration geochemistry in the Hercules area (see above).

8.3.5 Jupiter

A zone of intense alteration at the Jupiter prospect hosts two separate styles of mineralization. The Jupiter Pb - Zn horizon, a thin, probably stratiform galena - sphalerite band, occurs in strongly cleaved sericite schist within the broader zone of quartz - sericite altered tuffs. Further east, strongly silicified tuffs with disseminated pyrite contain stringers to semi - massive pyrite - chalcopyrite with a chlorite matrix.

North of Jupiter, a poorly defined altered zone was located during mapping. Strongly silicified tuff or lava, with quartz - replaced feldspar phenocrysts in a sericit - chlorite - altered matrix (TS 55079) is weakly pyritic. Drillhole BH 285, along strike of the known alteration, intersected strongly altered vitric tuffs adjacent to quartz - amygdaloidal lava or intrusive. A similar association is seen in drillhole CP 281 several kilometres to the north, which indicates the alteration is confined to a halo around the lava/intrusive, and is probably related to it.

	Average FW	Average FW (Fitzgerald 1974)	Average HR	Average HR (Fitzgerald 1974)	Hanging-wall	Average HW (Fitzgerald, 1974)
	(47173, 47174, 47175, 55525)	HR 49,68, 74,88,180	(55320, 55349)	HR 8,15,26, 32,55,60, 91,114,128 132,150,153	(55281)	HR 71,73,105, 141.
Al_2O_3	11.5	12.9	15.95	15.4	13.9	13.5
SiO_2	74.3	76.9	62.0	55.7	73.5	73.9
TiO_2	0.29	0.24	0.53	0.56	0.35	0.29
FeO	2.08	2.08	1.31	3.84	1.26	2.00
Fe_2O_3	1.81		1.13		1.15	
MnO	0.25	0.25	0.22	2.04	0.05	0.11
CaO	0.20	0.65	3.12	5.46	0.28	1.13
K_2O	3.70	2.75	3.90	3.95	2.40	2.20
MgO	1.24	0.63	4.20	3.50	0.85	1.29
Na_2O	0.06	0.15	0.36	0.62	3.74	2.40
P_2O_5	0.03	0.04	0.12	0.20	0.035	0.05
Cr_2O_3		0.36		0.08		
SO_3	1.56		1.35		0.03	
CO_2	0.45		2.90		0.15	
H_2O -	0.14		0.12		0.09	
H_2Ot	2.59		3.70		1.65	
LOI		4.10		9.46		3.86
Pb+Zn+Cu	0.08	0.36	0.01	0.48	0.01	0.01
Rb (ppm)	210		185		120	
Sr "	15		100		190	
Ba (ppm)	1100		3325		670	
Na_2O/K_2O	0.045	0.05	0.09	0.16	1.56	1.09
Sr/Rb	0.07		0.54		1.58	
MnO+CaO+MgO	1.69	1.53	7.54	11.0	1.10	2.53

TABLE 7 - Averaged Whole Rock Analyses of Footwall, Host and Hangingwall Rocks, Hercules Area.

8.4 ALTERED WHITE SPUR FORMATION

Tuffs within the wedge of White Spur Formation west of the Rosebery Fault at Rosebery, are strongly altered but in a different style to the footwall pyroclastics. These were termed the "massive siliceous rocks" by Naschwitz (1985), who also noted the difference between these and the "quartz schist" style of alteration.

This style of alteration is characterised by the massive, textureless nature, green to yellow appearance, extensive quartz ± carbonate veining, as shown in Fig. 63. In thin section, phenocrystal quartz and sericitized feldspar are present in a phyllitic or recrystallized granular silicified and sericitized groundmass, locally with shards (TS 54322). Minor pyrite often accompanies the alteration, and joints are often coated by bluish tourmaline.

Naschwitz (op. cit.) reported major element chemistry of ten "massive siliceous rocks" (Table 5) and discussed their distribution and relative enrichment/ depletion of various elements, when comparing altered rocks (combining **both** groups of Table 5) to unaltered rocks. The main chemical differences **between** the groups is that SiO_2 is considerably higher in massive siliceous rocks causing an apparent decrease in TiO_2, Fe_2O_3, MgO and CaO.

8.5 METASOMATIC ALTERATION

Within the Rosebery - Dalmeny area, and particularly at the southern end of F lens in the Rosebery mine, a number of assemblages reflect increasing metamorphic grade, and indicate the proximity of a ?Devonian granite.

The assemblages, although complex and overlapping, can be divided into the following groups:

1. Tourmaline - phlogopite - Fe oxide/sulphide
2. Be - silicates
3. Mn - Ca - Fe - silicates
4. Biotite - tourmaline
5. Quartz - tourmaline ± fluorite veins.

Fig. 63. Altered, strongly silicified, sericitized and veined White Spur Formation near the Rosebery Fault, (5374310N, 378150E).

8.5.1 Tourmaline - bearing Fe - rich Zone

F lens, Rosebery Mine

The southern termination of the Rosebery orebody (F lens south) is characterised by an auriferous, tourmaline - bearing massive sulphide zone, usually of pyrite and pyrrhotite, and an envelope of tourmaline - phlogopite - magnetite.

Toward the southern end of Flens, massive pyrite - pyrrhotite bodies (see also Section 6.2.4) with minor tourmaline and phlogopite, are in the order of 50m strike length and 15 m width, and on most levels below 14 level actually mark the termination of the massive sulphide deposit (sensu stricto). These bodies usually have contacts which show them to be replacive of Pb-Zn ore (eg. Brathwaite, 1969; Vokes, 1983). In detail, Pb-Zn ore becomes progressively enriched in Fe within about 10mm. of the contact, as the contact is approached. Sphalerite becomes much darker, with the increasing Fe content, and pyrite is coarser and more abundant. The contact is gradational over about 1 mm. (Vokes, 1983).

Thin quartz - tourmaline veins are frequent in the deeper part of the southern orebody, especially in the footwall, and lenses of bedded "tourmalinite" (or perhaps layered or replaced quartz- tourmaline rocks), are known from areas in close proximity to the pyrite - pyrrhotite bodies.

Vokes (1983) describes a number of textural relationships from these assemblages, such as porphyroblastic pyrite overprinting aggregates of tourmaline needles, relict mica - rich clasts intergrown with tourmaline, that confirm a post - ore origin, and complex paragenesis, of the metasomatic alteration.

A change occurs in the Fe - rich mineral assemblages, from oxidized magnetite - tourmaline - phlogopite, to reduced pyrite - pyrrhotite - tourmaline - phlogopite, where it is likely that massive sulphide ore has been replaced. This can be best explained by a reduction of the same fluids depositing the oxidized phase, to the pyrite - pyrrhotite phase in the presence of abundant sulphide.

The massive pyrite - pyrrhotite contains an erratic distribution of gold. Some areas contain sufficient gold (assays of between 4 and 30 g/t) to be a potential resource, while other areas are apparently barren. Relict chalcopyrite is present in most polished sections examined by the author, and along with un-replaced pyrite from the original ore, may contain enough gold to account for the given grades (G. Purvis, pers. comm.); alternatively a proportion of the gold may have been introduced with the replacing fluids, which is indicated by the presence of gold in the Rosebery Fault.

Dalmeny

At Dalmeny, some 2km south of Rosebery, a strongly altered biotite - tourmaline zone occurs immediately below a thin sulphide horizon in a sedimentary sequence. Massive green felted biotite, with sparse clusters of schorl, corroded adularia crystals, disseminations and stringers of magnetite, contains veins of quartz - carbonate - fluorite.

In tuffs below this zone, relatively weak alteration of a similar type has produced minor disseminated fine schorl, quartz - sulphide replaced feldspar, and quartz - adularia - muscovite - sulphide veinlets.

8.5.2 Be - Silicates

Two related assemblages have recently been documented by Cowan (1985) of unusual rocks collected by mine geologists, from 18 level F lens, and a drillhole beneath Flens:

Helvite - phlogopite - pyrrhotite - fluorite - spessartite, and

Mn carbonate - spessartite - magnetite - meliphanite.

Helvite 3(Mn, Fe) $BeSiO_4$. MnS, and meliphanite $(Ca, Na)_2 Be(Si, Al)_2(O, F)_7$ are both complex Be silicates, the former occasionally recorded from Mn - skarns elsewhere (see Sect. 9).

8.5.3 Mn - Ca - Fe - Silicates

Cowan (op. cit.) reports an assemblage of wollastonite - pyroxmangite - pseudowollastonite - spessartite from vein-like bands beneath Flens. Carbonate relics are preserved as inclusions in pyroxmangite. The reaction

MnCO3	+	SiO2	=	MnSiO3	+	CO2
rhodochrosite		quartz		pyroxmangite		

is inferred to have taken place.

A similar reaction leads to the formation of wollastonite.

CaCO3	+	SiO2	=	CaSiO3	+	CO2
calcite		quartz		wollastonite		

8.5.4 Biotite - tourmaline

A vein assemblage in the helvite - phlogopite - pyrrhotite rock contains later biotite - tourmaline - magnetite - siderite veins. Although retrogressive of the high temperature Be-silicate assemblage, this stage is probably a continuation of the earlier phlogopite - tourmaline - magnetite stage. Chlorite - apatite and quartz - chlorite veins are later and cross-cutting.

8.5.5 Quartz - tourmaline Veins

Quartz - tourmaline veins, and veinlets on cleavage and joint planes are ubiquitous in the Rosebery to Dalmeny area and west to the Rosebery Fault. Thin veins consist of bluish tourmaline (schorl) walls with a quartz core, while larger veins have massive tourmaline walls, a quartz core often with fluorite and sulphides (mainly pyrite, also arsenopyrite), and tourmaline - lined fractures and breccia zones.

8.5.6 Tourmaline Compositions

SEM probes provided by I. Plimer (written comm.) of various tourmaline from a range of localities and assemblages, are all Fe - rich schorl (Fig. 64), and plot in the field characteristic of granite - related tourmaline.

Recently, several authors have shown an association between tourmaline and tourmalinite with Proterozoic to Palaeozoic sediment- hosted stratabound ore deposits. Slack (1982), and Taylor and Slack (1984) detail the occurrence, characteristics and chemistry of tourmaline associated with Appalachian - Caledonian massive sulphide deposits, and Barnes (1983) and Plimer (1983) related stratiform tourmaline - rich rocks to mineralization in the Broken Hill area. Tourmaline from these areas appears to be Mg - rich dravite or Fe - rich schorl.

8.6 OTHER ALTERATION TYPES

Albitization

Extensive areas of pink tuffs with albitized feldspar phenocrysts in a fine quartzo-feldspathic and sometimes albitized matrix are present in the footwall pyroclastics and occasionally the quartz - phyric tuffs. Examples of this type of alteration are in the footwall pyroclastics in the Ring River valley, and at Bobadil in drillhole BD 269, where albitized feldspar in a fine- grained quartz- albite matrix is associated with chalcedonic, massive silicification.

This alteration style appears only to occur separate from hydrothermally altered areas.

Epidotization

Epidotization is normally associated with rocks of the right bulk chemistry (i.e. Ca - rich, usually intermediate to basic rocks). Epidote was noted only in a few localities, and generally as

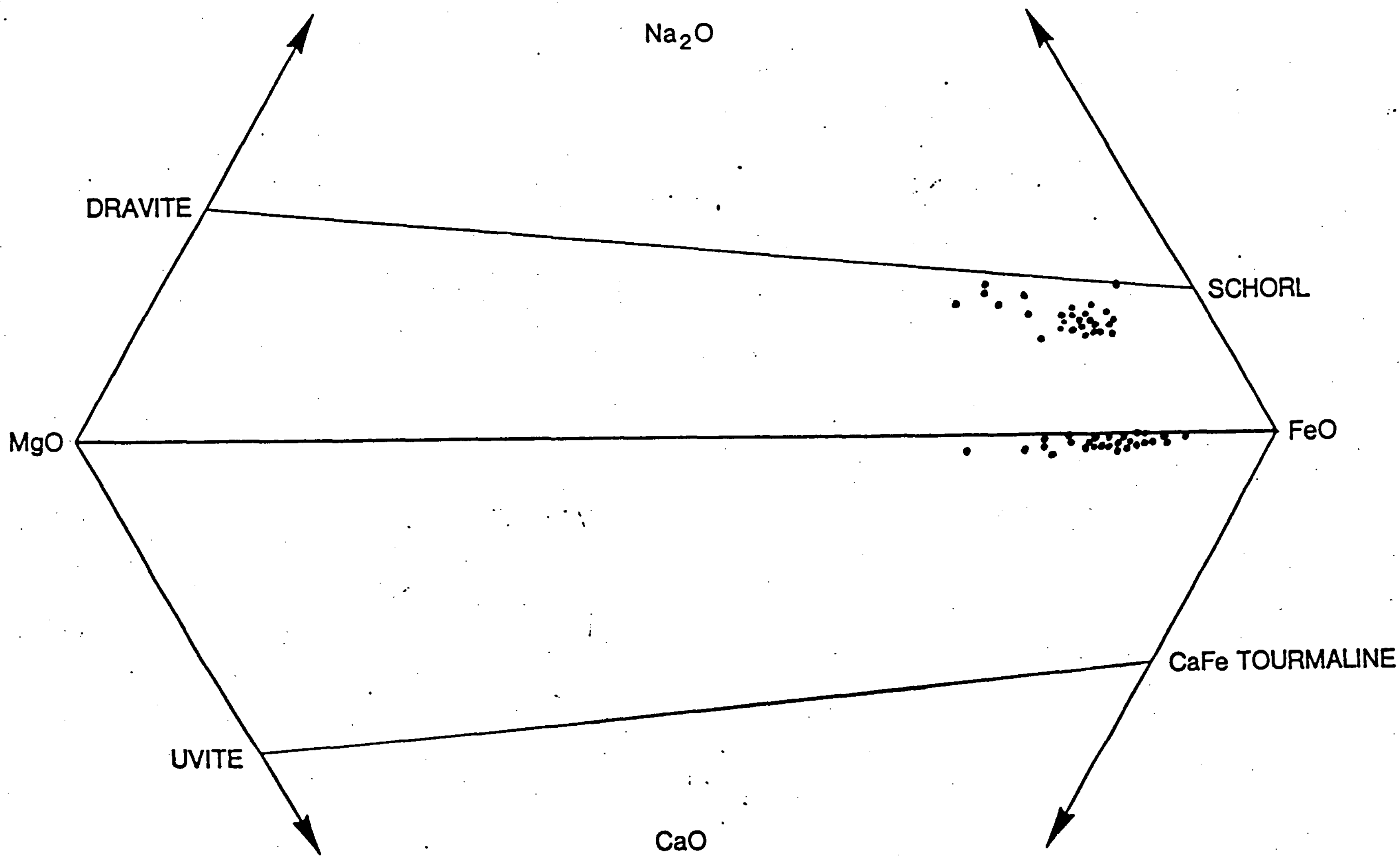


FIGURE 64 - Compositional Plots of Tourmaline from the Rosebery Area
(Analysed by I. Plimer)

a fine vein - network in the same areas as extensive albitization.

Chloritization

Chloritization of mafic minerals in basalts and andesites is ubiquitous. Zones of extensive chloritization occur in the footwall of massive sulphide deposits, but are discussed above.

9 METAMORPHISM

9.1 REGIONAL METAMORPHISM

Brathwaite (1969) noted the following assemblages in the Rosebery area:

1) quartz - muscovite - chlorite in the "Munro Creek Slates",

2) quartz - albite - sericite - chlorite- sphene in the "Primrose Pyroclastics",

3) albite - quartz - chlorite - sericite - epidote - sphene in the Mt. Black Volcanics,

and concluded that greenschist facies of regional metamorphism had been reached.Whitford (1984) recognised regional prehnite - pumpellyite facies metamorphism at Que River, with mainly quartz - sericit e- chlorite - carbonate assemblages present (Wallace, 1984).

At Mt. Lyell, Cox (1981) recorded the following assemblages:

1) quartz - albite - phengitic mica - chlorite $\pm$ K feldspar $\pm$ calcite in silicic rocks, and

2) chlorite - albite - actinolite - epidote - quartz in intermediate to mafic rocks,

and concluded that low grade metamorphic conditions, of approximately 2 kbar pressure and temperature less than 350° C had been attained. The assemblages at Mt. Lyell are similar to those at Rosebery.

Eastoe (1981) related sporadic biotite occurrences in the Rosebery area, known tourmaline occurrences, and sites with vein- style tin mineralization, to a belt of suspected Devonian granite lying beneath and linking the granite outcrops at High Tor, Pine Hill, and the Heemskirk Granite west of Zeehan. Granite beneath Colebrook Hill, on the same trend, was recently intersected in the Department of Mines drillhole (P. Collins, in prep.). The granite assumed to lie below Rosebery is thought to be responsible for the metasomatic alteration described in Section 8.3, in the Rosebery - Dalmeny area.

9.2 METAMORPHIC ASSEMBLAGES

9.2.1 Rosebery area

Stable assemblages present in the Rosebery area, where unaffected by the overprinting metasomatic alteration are:

- quartz - albite - sericite in the footwall pyroclastics
- quartz - sericite - chlorite $\pm$ carbonate in "quartz- schist" alteration
- chlorite - albite - epidote - sphene - quartz - sericite in the Mt. Black Volcanics.

Metasomatic assemblages, show prograde and retrograde stages:

pre - metasomatic - quartz - sericite - albite - chlorite - carbonate;

transitional - quartz - sericite - albite - chlorite - biotite;

prograde - quartz - chlorite - garnet - biotite - muscovite - tourmaline (Green, 1983),
- wollastonite - pyroxmangite - pseudowollastonite - spessartine(Cowan, 1985)
- helvite - phlogopite - spessartite - fluorite - pyrrhotite (Cowan, 1985),
- carbonate - spessartite - magnetite - meliphanite (Cowan, 1985.),

retrograde - biotite - tourmaline - magnetite - siderite,
- prehnite - calcite, chlorite - apatite and quartz (Cowan, 1985).

9.2.2 Granite - related Assemblages in Western Tasmania

A number of granit e- related skarn - type deposits are known in western Tasmania, and their prograde assemblages are briefly reviewed for comparison with the assemblages in the Rosebery mine - Dalmeny area.

Renison

Patterson et al. (1981) report assemblages of Stage 1: quartz- cassiterite - tourmaline ± magnetite, ilmenite, rutile, phlogopite, siderite, tremolite and Stage 11: pyrrhotite - dolomite - quartz - cassiterite - arsenopyrite - phlogopite - tremolite.

Cleveland

Collins (1981) describes vein and replacement parageneses at Cleveland in several stages. Stage 1: quartz - fluorite - wolframite - molybdenite; Stage 2: quartz - tourmaline - chlorite - fluorite - cassiterite - dolomite - pyrite - pyrrhotite - chalcopyrite; and Stage 3: quartz - arsenopyrite - chlorite - fluorite - stannite.

Colebrook Hill

At Colebrook Hill west of Rosebery, assemblages documented in EZ reports are 1: axinite - grossular/andradite garnet - hedenbergite - ferrohastingite, and 2: tourmaline - axinite - actinolite - quartz - sphene - pyrrhotite.

Mt. Lindsay

Kwak (1983) reports assemblages Stage 1A: magnetite - siderite - K feldspar - ilmenite - cassiterite ± danalite, fluorite; and Stage 1B: vesuvianite - garnet - calcite.

Pine Hill

Ward (1981) describes greisen at Pine Hill as composed of quartz, tourmaline, mica which may be accompanied by topaz, fluorite, cassiterite, wolframite and molybdenite.

Mt. Ramsay

P. Collins (pers. comm.) reports helvite from skarn assemblages at Mt. Ramsay.

9.3 CONDITIONS OF METAMORPHISM

Green (1983) used several methods to try to determine the metamorphic conditions. Co-existing garnet and biotite, isotopic fractionation beween pyrite and pyrrhotite, and arsenopyrite- fahlore relationships, were used by Green (op. cit.) to derive a temperature range of 350° C < T < 400° C during the Devonian metamorphism, and attributed a temperature of 250° C from pyrite - arsenopyrite - chlorite equilibria to waning metamorphic conditions. It is now apparent that the range of temperatures are at least in part due to the influence of post-metamorphic metasomatic alteration.

Green (op. cit.) calculated the pressure during metamorphism using sphalerite in pyrrhotite, and deduced a pressure range of 3.1 to 5.2 kbar, although this may be invalid as monoclinic pyrrhotite was shown to be present, and again the pyrrhotite assemblage is known to have been formed by metasomatic alteration.

10 CONCLUSION

Geological relationships on the western margin of the Mt. Read Volcanics in the Rosebery - Hercules have been established by Corbett and Lees (in press) and in this thesis. The Dundas Group, with the largely epiclastic White Spur Formation at the base, is represented by Stitt Quartzite, Westcott Argillite, Natone Volcanics and Salisbury Conglomerate, and unconformably overlies the Mt. Read Volcanics. The Mt. Read Volcanics have been thrust over the Dundas Group along the Rosebery Fault.

The volcano - sedimentary sequence at the base of the known Mt. Read Volcanics, containing the Rosebery and Hercules orebodies, is interpreted in terms of stages in the development of a caldera. The footwall pyroclastics are pumiceous, feldspar - phyric ash flow tuffs having features consistent with current models of pyroclastic flow deposits, and are considered to be the products of caldera-forming eruptions.

Rapid subsidence during caldera subsidence initiated deposition of widespread sediments (the host rocks), and triggered the ore - forming process. A change in style of volcanism, reflected in the change from feldspar to quartz-plus-feldspar mineralogy, also occurred at this point.

The hangingwall epiclastics were deposited as a series of mass flows which interrupted a quiet sedimentary regime. Features indicative of this, such as lithic - rich basal breccias, grading through massive tuff to reworked, bedded volcanogenic sandstones, and finally shales at the top of the unit representing the quiet regime, are present. Resurgence of the caldera during deposition of the epiclastics is evidenced by systematic variation in along - strike thickness, and curvature of the host rock position relative to the top of the epiclastic sequences.

Overlying the hangingwall epiclastics are the Mt. Black Volcanics, a thick sequence of massive dacite and andesite lavas with minor tuffs, epiclastics and sediments.

The White Spur Formation at the base of the Dundas Group is seen to overlie the Mt. Read Volcanics unconformably south and west of Hercules. A thick sequence of epiclastic mass flows, similar to the hangingwall epiclastics, with an upwardly increasing proportion of interbedded shale and siltstone, culminates in the Chamberlain Shale member at the top of the formation. The Stitt Quartzite, of thinly to thickly interbedded quartzwacke and shale - siltstone, follows conformably, and is succeeded by the Westcott Argillite of dolomitic siltstones, dolomite and minor conglomerate. At the top of the exposed sequence the Natone Volcanics, consisting of felsic tuffs, and Salisbury Conglomerate, interfinger.

Structure of the area is dominated by the Rosebery Fault, an east - dipping thrust with a minimum throw of 1.5 km. East of the fault, cleavage has a consistent moderate east dip, while west of the fault cleavage is steeply dipping, and a number of tectonic melange zones are present within a disrupted sequence. Transposition has affected the orebodies at Rosebery and Hercules, particularly the latter where the ore lenses are oriented within the cleavage.

Several styles of mineralizaton are present in the area, the main type being the stratiform, volcanogenic massive sulphide deposits at Rosebery and Hercules. A thin, discontinuous mineralized horizon occurs within the footwall pyroclastics, some 400 metres stratigraphically below the Hercules mineralization at Ring P. A. and Jupiter. Stringer mineralization at Koonya appears to be related to an alteration zone within the footwall pyroclastics, while vein - style mineralization at Dalmeny is related to small intrusives. The Rosebery Fault near Rosebery contains a quartz - tourmaline vein assemblage with minor gold related to a later Devonian granite intrusion.

The Rosebery orebody is a major deposit of about 20 Mt at a grade of 5% Pb, 16% Zn, 0.3% Cu, 160 g/t Ag and 2.7 g/t Au. The basal lead - zinc orebody at Rosebery lies within the host rocks but directly above the footwall pyroclastics, which are strongly silicified and sericitized in the vicinity of the orebody. Brathwaite (1969) regarded the lead-zinc ore as a single stratigraphic horizon, but this may be an over - simplification as the ore position appears to vary relative to the footwall pyroclastic - host rock contact. A chalcopyrite - pyrite - magnetite - chlorite stringer zone beneath F lens (approx. 21 level) is of limited extent, but illustrates the presence of at least one major vent zone. Massive chalcopyrite - pyrite is commonly present below banded galena - sphalerite - pyrite ore, and probably represent zones of hydrothrmal discharge where fluids have migrated both upwards and laterally through the footwall pyroclastics. The barite ore is usually at a separate, stratigraphically higher position, but in F lens, barite is present in the upper part of the only ore horizon.

The Hercules Mine has recently been closed, having produced about 2.3 Mt at a similar grade to Rosebery. It consists of a number of *en echelon* lenses transposed parallel to the cleavage. Porphyroblastic ore textures are indicative of recrystallization and annealing, but some textures of "spotty ore" indicate a replacement or epigenetic origin for some of the sulphides. Zoning of the ore lenses from massive galena- sphalerite, down - dip to massive pyrite, then a chalcopyrite - pyrite stringer zone, indicates transposition of at least one originally stratiform massive sulphide lens. A small precious metal deposit at South Hercules consists mainly of disseminated, spotty sulphides, and quartz - sulphide veins.

Rosebery Lodes appears to be a smaller version of Rosebery but with only minor mineralization, while at Koonya stringer-style chlorite - pyrite - chalcopyrite, and galena - sphalerite veins occur in altered footwall pyroclastics well below the Rosebery horizon. Mineralization at Dalmeny and East Hercules is probably related to porphyritic intrusives.

A quartz - tourmaline vein system, best developed in the Rosebery Fault, contains minor Au with anomalous Cu, Sn, Bi and W, and was probably deposited by fluids active during intrusion of granite in the ?late Devonian. Also related to the granite is extensive metasomatism responsible for gold-bearing pyrite - pyrrhotite, and related tourmaline - magnetite - pyrite assemblages in F lens at Rosebery.

11 REFERENCES

Adams, C. J., Black, L. P., Corbett, K. D., and Green, G. R., 1985. Reconnaissance isotopic studies bearing on the tectonothermal history of Early Palaeozoic and Late Proterozoic sequences in western Tasmania; Aust. Jour. Earth Sci., vol. 32: pp 7 - 36.

Allen, R. L., 1986. Alteration- modified textures in silicic lavas with implications for volcanic- hosted mineralization; Geol. Soc. Aust., Abs. No. 15, 8th AGC.

Anderson, W. B., 1972. The Mt. Read Volcanics in the Rosebery - Tullah area; B. Sc. (Hons.) Thesis, Univ. of Tas., Unpub.

Banks, M. R., 1956. The Middle and Upper Cambrian series (Dundas Group and its correlates) in Tasmania; in Rodgers, J. (ed.) El sistema Cambrico, su paleogeografia y el problema de su base; XX Congreso Geologico Internacional, Mexico 1956: pp 165 - 212.

Barnes, R. G., 1983. Stratiform and stratabound tungsten mineralisation in the Broken Hill Block, Australia; J. Geol. Soc. Aust.: v 30 (2), pp 225-240.

Brathwaite, R. L., 1969. The geology of the Rosebery ore deposit; Ph. D Thesis, Univ. of Tas., Unpub.

Brathwaite, R. L., 1972. The structure of the Rosebery ore deposit, Tasmania; Aust. I. M. M. Proc., vol. 241: pp 1 - 14.

Brathwaite, R. L., 1974. The geology and origin of the Rosebery ore deposit, Tasmania; Econ. Geol., vol. 69: pp 1086 - 1101.

Brown, A. V., 1982. A geological cross- section of the Dundas Trough (Pieman Road); in Green, D. C., (ed.) Geology, mineralisation, exploration: Western Tasmania; Geol. Soc. Aust. Tas. Div., Dept. Mines Tas.: pp 38 - 42.

Burton, C. C. J., 1975 A. Rosebery lead- zinc orebody; in Knight, C. L., (ed.) Economic Geology of Australia and Papua New Guinea; Aust I. M. M. Mon. 5: pp 619 - 626.

Burton, C. C. J., 1975 B. Hercules and Farrell orebodies, Rosebery district; in Knight, C. L., (ed.) Economic Geology of Australia and Papua New Guinea; Aust I. M. M. Mon. 5: pp 626 - 628.

Campana, B., and King, D., 1963. Palaeozoic tectonism, sedimentation and mineralization in West Tasmania; Jour. Geol. Soc. Aust., vol. 10 (1): pp 1 - 54.

Campana, B., King, D., and McKenna, D., 1960. Unconformable units of the Cambrian succession of West Tasmania; Aust. J. Sci., vol. 20: pp 240 - 242.

Carey, S. N., and Sigurdsson, H., 1980. The Roseau Ash: Deep-sea tephra deposits from a major eruption on Dominica, Lesser Antilles arc: J. Volcanol. Geotherm. Res.; v. 7, pp 67-86.

Cas, R. A. F., and Wright, J. V., 1983. Modern and ancient volcanic successions; course notes, Dept. Earth Sci., Monash Univ.; Unpub.

Collins, P. L. F., 1981. The geology and genesis of the Cleveland tin deposit, western Tasmania: fluid inclusion and stable isotope studies; Econ. Geol., vol. 76: 365 - 392.

Collins, P. L. F., Gulline, A. B., and Williams, E., (comp.) 1981. Geological atlas one mile series. Sheet 44 (8014N) Mackintosh; Explan. Rep. Dept. Mines Tasm.

Cook, . and Mullins, . ., 1983. Carbonate Depositional Environments; AAPG Mem. 51.

Corbett, K. D., 1979. Stratigraphy, correlation and evolution of the Mt. Read Volcanics in the Queenstown, Jukes- Darwin and Mt. Sedgwick areas; Geol. Surv. Bull. 58, Dept. Mines Tasm.

Corbett, K. D., 1981. Stratigraphy and mineralization in the Mt. Read Volcanics, Western Tasmania; Econ. Geol., vol. 76: pp 209 - 230.

Corbett, K. D., 1984. Geological maps and summary of the Cambrian stratigraphic units and relationships in the Henty River- Williamsford area; Tas. Dept. Mines. Unpub. Rep. 1984/84.

Corbett, K. D., 1985. Geological compilation map of the Mount Read Volcanics, Que River to Mt. Darwin; Tas. Dept. Mines. Unpub. Rep. 1985/11.

Corbett, K. D., Reid, K. O., Corbett, E. B., Green, G. R., Wells, K., and Sheppard, N. W., 1973. The Mt. Read Volcanics and Cambrian- Ordovician Relationships at Queenstown, Tasmania; Jour. Geol. Soc. Aust., vol. 21 (2): pp 173 -186.

Corbett, K. D., and Lees, T. C., in press. Jour. Geol. Soc. Aust.

Cox, K. G., Bell, J.D., and Pankhurst, R. J., 1979. The Interpretation of Igneous Rocks; George Allen & Unwin.

Cowan, D., 1985. Petrological report CMS 85/9/23 to EZ; Unpub.

Cox, S. F., 1981. The stratigraphic and Structural Setting of the Mt. Lyell Volcanic- Hosted Sulfide Deposits; Econ. Geol., vol. 76: pp 231 - 245.

Crook, K. A. W., 1980A. Fore- arc evolution in the Tasman Geosyncline: the origin of the southeast Australian continental crust; Jour. Geol. Soc. Aust., vol. 27 (2): pp 215 - 232.

Crook, K. A. W., 1980B. Fore- arc evolution of continental growth: a general model; Jour. Struct. Geol., vol. 2: pp 289 - 303.

Crook, K.A.W., 1982. Fore-arc evolution and continental growth: a general model; J. Struct. Geol.; v. 2(3), pp 289-303.

Davis, G. H., 1972. Deformational History of the Caribou Strata- bound Sulphide Deposit, New Brunswick, Canada; Econ. Geol., vol. 67: pp 634 - 655.

de Rosen-Spence, A. F., Provost, G., Dimroth, E., Gochnauer, K., and Owen, V., 1980. Archean subaqueous felsic flows, Rouyn- Noranda, Quebec, Canada, and their Quaternary equivalents; Precamb. Res., vol. 12: pp 43 - 77.

Dixon, G. H., 1980. Geological, geochemical and stable isotope studies of the carbonates of the Rosebery ore deposit; B. Sc. (Hons.) Thesis, Univ. of Tas., Unpub.

Eastoe, C. J., 1973. Geological and geochemical variation in the Rosebery host rock horizon; B. Sc. (Hons.) Thesis, Univ. of Tas., Unpub.

Eastoe, C. J., 1980. Report on field work on alteration studies on the E. Z. and Mt. Lyell areas February to June 1980; Report to EZ; Unpub.

Eastoe, C. J., 1981. Alteration and mineralisation in the Mt. Read Volcanics, western Tasmania; Report to EZ; Unpub.

Eldridge, C. S., Barton, P. B. Jnr., and Ohmoto, H., 1983. Mineral textures and their bearing on formation of the Kuroko orebodies; in Ohmoto, H., and Skinner, B. J., (eds.) The Kuroko and related massive sulphide deposits; Econ. Geol. Mon. 5: pp 241 - 281.

Elliston, J., 1954. Geology of the Dundas District, Tasmania; Pap. Proc. Roy. Soc. Tas., vol. 88: pp 161 -183.

Fander, H. W., 1973. Petrological report CMS 73/8/22 to E.Z.; Unpub.

Finucane, K. J., 1932. Preliminary report on geological survey of the Rosebery district, Tasmania, parts I, II; Chem. Engg. Min. Rev., vol. 25: pp 5 - 7, 43 - 46.

Fisher, R. V., and Schmincke, H.-U., 1984. Pyroclastic Rocks; Springer- Verlag.

Fitzgerald, F. G., 1974. The Primrose Pryoclastics in the Hercules- White Spur area, Western Tasmania; B. Sc. (Hons.) Thesis, Univ. of Tas., Unpub.

Francis, E.H., and Howells, M.F., 1983. Transgressive welded ash-flow tuffs among the Ordovician sediments of N.E. Snowdonia; J. Geol. Soc. Lond., v. 129, pp 612-641.

Furnes, H., Fridleifsson, I. B., and Atkins, F. B., 1980. Subglacial volcanics - on the formation of acid hyaloclastites; Jour. Volcanol. Geotherm. Res., vol. 8: pp 95 - 110.

Furnes, H., and Sturt, B. A., 1976. Beach/ shallow marine hyaloclastite deposits and their geologic significance - an example from Gran Canaria; Jour. Geol., vol. 84: pp 439 - 453.

Gee, C. E., 1970. The geochemistry of some black shales in relation to the origin of certain stratiform orebodies in Tasmania; Ph. D. Thesis, Univ. of Tas., Unpub.

Green, G. R., 1983. The geological setting and formation of the Rosebery volcanic- hosted massive sulphide orebody, Tasmania; Ph. D. Thesis, Univ. of Tas., Unpub.

Green, G. R., Solomon, M., and Walshe, J. L., 1981. The formation of the volcanic- hosted massive sulphide ore deposit at Rosebery, Tasmania; Econ. Geol., vol. 76: pp 304 - 338.

Haas, J. L., 1971. The effect on salinity on the maximum thermal gradient of a hydrothermal system at hydrostatic pressure; Econ. Geol., vol. 66: pp 940 - 946.

Hall, G., Cottle, V. M., Rosenhain, P. B., and McGhie, R. R., 1953. Lead- zinc ore deposits of Read- Rosebery and Mt. Farrell; in Edwards, A. B., (ed.) Geology of Australian ore deposits; 5th Emp. Min. Metall. Cong.: pp 1145 - 1159.

Hall, G., Cottle, V. M., Rosenhain, P. B., McGhie, R. R., and Druett, J. G., 1965. Lead- zinc ore deposits of Read - Rosebery; in McAndrew, J., (ed.) Geology of Australian ore deposits; Aust. I. M.M. Eighth Comm. Min. Metall. Cong.: pp 485 - 489.

Hall, R. J., 1967. The geology of the Hercules mine area, Williamsford; B. Sc. (Hons.) Thesis, Univ. of Tas., Unpub.

Harley, D. N., 1979. A mineralized Ordovician resurgent caldera complex in the Bathurst- Newcastle mining district, New Brunswick, Canada; Econ. Geol., vol. 74: pp 786 - 796.

Hills, L., 1915. The zinc- lead sulphide deposits of the Read- Rosebery District; Tas. Geol. Surv. Bull., no. 19: 98 p.

Huston, D. L., and Large, R. R., 1986. The distribution, mineralogy and geochemistry of precious metals in the north-end orebody, Rosebery mine, Tasmania; Univ. of Tasm., Unpub.

Ishikawa, Y., Sawaguchi, T., Iwaya, S., and Horiuchi, M., 1976. Delineation of prospecting targets for Kuroko deposits based on modes of volcanism of underlying dacite and alteration haloes: Min. Geol. vol. 30; pp 187-194 (English abs.).

Kouda, R., and Koide, H., 1978. Ring structures, resurgent cauldron, and ore deposits in the Hokuroko Volcanic Field, northern Akita, Japan; Mining Geol., vol. 28: pp 233 - 244.

Kwak, T. A. P., 1983. The geology and geochemistry of the zoned Sn- W- F- Be skarns at Mt. Lindsay, Tasmania, Australia; Econ. Geol., vol. 78: pp 1440 - 1465.

Lambert, M. B., 1974. The Bennett Lake Subsidence Complex, British Colombia and Yukon Territory; Geol. Surv. Can. Bull., No. 227.

Lees, T. C., 1985. Geology of the Hercules orebody, Tasmania; E. Z. Report No. T201: Unpub.

Lees, T. C., and Howarth, J. W., in prep. The geology of the Hercules ore deposit.

Lipman, P. W., 1975. Evolution of the Platoro Caldera Complex and related volcanic rocks, southeastern San Juan Mountains, Colorado; U.S.G.S. Proff. Pap. 852: pp 1 - 128.

Lipman, P. W., 1984. The roots of ash flow calderas in western North America: windows into the tops of granitic batholiths; Jour. Geophys. Res., vol. 89 no. B10: pp 8801 - 8841.

Loftus-Hills, G., Solomon, M., and Hall, R. J., 1967. The structure of the bedded rocks west of Rosebery, Tasmania; Jour. Geol. Soc. Aust., vol. 14 (2): pp 333 - 337.

Lowman, R. D. W., and Bloxam, T. W., 1981. The petrology of the Lower Paleozoic Fishguard Volcanic Group and asociated rocks E of Fishguard, N. Pembrokeshire (Dyfed), South Wales; J. Geol. Soc. London, 138: pp 47 - 68.

McDonald, I. R., 1985. A geological compilation of the Mount Read Volcanics belt, Tasmania; E.Z. Geol. Dept. Report T211; Unpub.: 16p.

McKee, E.H., 1979. Ash-flow sheets and calderas: Their genetic relationship to ore deposits in Nevada: Geol. Soc. Am. Spec. Pap. 180, pp 205-211.

Mill, J. H. A., 1983. Exploration at Rosebery, Tasmania 1947 - 1983; M.M.I.J./Aus. I.M.M. Joint Symposium 1983. Sendai: pp 79 - 94.

Mill, J. H. A., McDonald, I. R., and Weeden, R. J., 1980. Mt. Black Exploration Licence 1/62, report on work undertaken 30th June 1979 - 30th June 1980; E.Z. Geol. Dept. Report 134; Unpub.: 63p.

Mutti, E., 1965. Submarine flood tuffs (ignimbrites) associated with turbidites in Oligocene deposits of Rhodes Island (Greece); Sedimentology, vol. 5: pp 265 - 268.

Naschwitz, W., 1985. Geochemistry of the Rosebery ore deposit; Ph. D. Thesis, Univ. of Tas.; Unpub.

Noble, D. C., and McKee, E. H., 1982. Nevado Portugueza volcanic centre, Central Peru: a Pliocene central volcano- collapse caldera complex with associated silver mineralization; Econ. Geol., vol. 77: pp 1893 - 1900.

Ohmoto, H., 1978. Submarine calderas: a key to the formation of volcanogenic massive sulphide deposits ?; Mining Geol., vol. 28; pp 219 - 231.

Ohmoto, H., and Takahashi, T., 1983. Geologic setting of the Kuroko deposits, Japan; Part III. Submarine calderas and Kuroko genesis; in Ohmoto, H., and Skinner, B. J., (eds.) The Kuroko and related massive sulphide deposits; Econ. Geol. Mon. 5: pp 35 -54.

Patterson, D. J., Ohmoto, H., and Solomon, M., 1981. Geologic setting and genesis of cassiterite- sulphide mineralization at Renison Bell, western Tasmania; Econ. Geol., vol. 76: pp 393 - 438.

Peterson, D.W., 1970. Significance of the flattening of pumice fragments in ash-flow tuffs; Geol. Soc. Am. Spec. Pap. 180; p 185 ff.

Plimer, I. R., 1981. Water depth - a critical factor for exhalative ore deposits; BMR Jour. Aust. Geol. Geophys., vol. 6: pp 293 - 300.

Plimer, I.R., 1983. The association of tourmaline-bearing rocks with mineralisation at Broken Hill, N.S.W.: Aus. I.M.M. Con. Proc. 1983; pp 157-176.

Reinhardt, D., 1972. Report on exploration in EL 1/62 Mt. Black carried out during 1971-72; E.Z. Geol. Dept. Report 108; Unpub.: 14 p.

Ridge, J. D., 1974. Note on boiling of ascending ore fluids and the position of volcanic-exhalative deposits in the modified Lindgren classification; Geology, vol. 2: pp 287 - 288.

Ross, C. S., and Smith, R. L., 1961. Ash flow tuffs: their origin geologic relations and identification; U.S.G.S. Proff. Pap. 366: 81p.

Rupke, N. A., 1977. Growth of an ancient deep-sea fan; Jour. Geol.,vol. 85: pp 725 - 744.

Sillitoe, R. H., 1982. Extensional habitats of rhyolite- hosted massive sulfide deposits; Geology, vol. 10: pp 403 - 407.

Slack, J.F., 1982. Tourmaline in Appalachian-Caledonian massive sulphide deposits and its exploration significance; Trans. I.M.M. (Sect.B) vol. 91, pp 81-89.

Smith, J. H., 1898. Report on the mineral fields in the neighbourhood of Mt. Black, Ringville, Mt. Read, and Lake Dora; Report of the Secretary for Mines for 1897-8; Parliament of Tasmania.

Smith, R. L., and Bailey, R. A., 1968. Resurgent cauldrons; in Coats, R. R., Hay, R. L., and Anderson, C. A., (eds.); Studies in volcanology (Howell Williams Volume); Geol. Soc. Am. Mem. 116.

Smith, R. N., 1975. Precious and volatile metal distribution in the ores and host rocks of the Rosebery ore deposit, Tasmania; B. Sc. (Hons.) Thesis, Univ. of Melb., Unpub.

Solomon, M., 1960. The Dundas Group in the Queenstown area; Pap. Proc. Roy. Soc. Tas., vol. 94: pp 33 - 59.

Solomon, M., 1964. The spilite- keratophyre association of West Tasmania and the ore deposits at Mt. Lyell, Rosebery and Hercules; Ph. D. Thesis, Univ. of Tas., Unpub.

Solomon, M., 1965. Geology and mineralization of Tasmania; in McAndrew, J., (ed.) Geology of Australian ore deposits; Aust. I. M.M. Eighth Comm. Min. Metall. Cong.: pp 464 - 477.

Solomon, M., and Griffiths, J. R., 1972. Tectonic evolution of the Tasman orogenic zone, eastern Australia; Nature, 237: pp 3 - 6.

Solomon, M., Rafter, T. A., and Jensen, M. L., 1969. Isotope studies on the Rosebery, Mount Farrell and Mount Lyell ores, Tasmania; Mineral. Deposita (Berl.), vol. 4: pp 172 - 199.

Solomon, M., Vokes, F. M., and Walshe, J. L., in press. Chemical remobilization of volcanic- hosted sulphide deposits at Rosebery and Mt Lyell, Tasmania.

Solomon, M., and Walshe, J.L., 1979. The formation of massive sulphide deposits on the sea floor; Econ. Geol., v.74; pp 797-813.

Sparks, R. S. J., and Huang, T. C., 1980. The volcanological significance of deep- sea ash layers associated with ignimbrites; Geol. Mag., vol. 117 (5): pp 425 - 436.

Sparks, R. S. J., Sigurdsson, H., and Carey, S. N., 1980. The entrance of pyroclastic flows into the sea, I. Oceanographic and geologic evidence from Dominica, Lesser Antilles, and II. Theoretical considerations on subaqueous emplacement and welding; J. Volcanol. Geotherm. Res., vol. 7: pp 87 - 96, 97 - 105.

Steven, T. A., Luedke, R. G., and Lipman, P. W., 1974. Relation of mineralization to calderas in the San Juan Volcanic Field, southwestern Colorado; Jour. Research U.S.G.S., vol. 2 (4): pp 405 - 409.

Stillwell, F. L., 1934. Observations on the zinc-lead lode at Rosebery, Tasmania; Proc. Aust. I. M. M., no. 94: pp 43 - 67.

Taylor, B.E., and Slack, J.F., 1984. Tourmalines from Appalachian-Caledonian massive sulphide deposits: textural, chemical, and isotopic relationships; Econ. Geol., vol. 79, pp 1703-1726.

Throop, A. H., 1974A. Exploration of the South Hercules area 1973; E.Z. Geol. Dept. Report 112; Unpub.

Throop, A. H., 1974B. Geological work done at Hercules mine and North Hercules in 1972 - 1974; E.Z. Geol. Dept. Report 116; Unpub.

Vokes, F. M., 1983. Paragenetical and textural relations in the south end of F lens (16 level), Rosebery mine, Tasmania; prelim. report to B.M.R., Unpub.: 40 p.

Wallace, D.B., 1984. Developments in the geological understanding of the Que River deposit; in Baillie, P.W., and Collins, P.L.F., (eds.) Mineral exploration and tectonic processes in Tasmania; Abs. Vol; Geol. Soc. Aust., Tasm. Div., Hobart.

Waller, G. A., 1902. Report on the ore deposits (other than those of tin) of north Dundas; Report of the Secretary for Mines for 1901-1902; Parliament of Tasmania.

Ward, M. A., 1981. The geology of the granites at Renison Bell - Pine Hill (Pine Hill Intrusive Group); B. Sc. (Hons.) Thesis, Univ. of Tas., Unpub.

Weeden, R. J., 1981. A review of exploration in the Black P. A. area; E.Z. Geol. Dept. Report 136; Unpub.: 10 p.

Whitford, D. J., 1984. Geochemistry of alteration around the Que River orebodies; in Baillie, P. W., and Collins, P. L. F., (eds.) Mineral exploration and tectonic processes in Tasmania; Geol. Soc. Aust. Tas. Div., Dept. Mines Tas.: pp 57 - 58.

Williams, K. L., 1960. Some less common minerals in the Rosebery and Hercules zinc-lead ores; Proc. Aust. I. M. M., no. 196: pp 51 - 60.

Williams, E., 1976. Tasman fold belt system in Tasmania; Explan. Notes, Dept. Mines Tas.

Williams, R. E., 1974. Progress report on exploration of Exploration Licence 1/62 (Mt Black) during 1973-74; E.Z. Geol. Dept. Report 117; Unpub.: 16 p.

Wright, J.V., and Coward, M.P., 1977. Rootless vents in welded ash-flow tuffs from northern Snowdonia, North Wales, indicating deposition in a shallow water environment; Geol. Mag., 114, pp 133-140.

Wright, J.V., and Mutti, E., 1981. The Dali Ash, Island of Rhodes, Greece: A problem in interpreting submarine volcanogenic sediments; Bull. Volcanol., vol. 44, p 153 ff.

Appendix 1

Thin section identifications and sample locations.

EZ Sample No	Description	Location (A.M.G or DDH co-ords)
P1	Silicified quartz-feldspar-phyric tuff	5371840N, 377680E
P4	Lithic breccia	5369890N, 376550E
47143	Brecciated dacite lava	45 R 582'
47144	Quartz-feldspar-phyric tuff	45 R 865'
47145	Quartz-feldspar-phyric tuff	45 R 1202'
47146	Quartz-feldspar-phyric tuff	48 R 410'
47149	Quartz-feldspar-phyric tuff	48 R 737'
47150	Limestone	57 R -D1 703'
47152	Quartz-feldspar-phyric tuff	60 R 3028'
47153	Quartz-feldspar-phyric tuff	60 R 3084'
47156	Andesite lava, chloritized mafic phenocrysts	71 R 827'
47157	Quartz-feldspar-phyric tuff	71 R 1780'
47158	Quartz-feldspar-phyric tuff	71 R 1900'
47161	Lava-breccia, lava fragments in fine matrix	72 R 90.5m
47162	"Spotty ore", sulphide spots in silicified tuff matrix	Hercules A lode
47163	Quartz-phyric lithic tuff	DP 85 264'
47164	Pelitic ash	RLP 178 260
47166	Vitric tuff	JP 204 105'
47168	Quartz-feldspar-phyric lava/intrusive	5378000N, 378100E
47173	Silicified pumiceous tuff	Hercules, 7L drive, 3S
47174	Silicified pumiceous tuff	Hercules, 7L, 1S XC
47175	Silicified pumiceous tuff	5367730N, 376360E
54003	Feldspar-phyric tuff	5374090N, 378590E
54302	Sericitized feldspar-phyric dacite lava	5373870N, 379 175E
54350	Feldspar-phyric tuff or lava	5372497N, 378470E
54490	Tourmalinized quartzite	5373085N, 378923E
54513	Quartz-feldspar-phyric tuff	5372345N, 379075E
54621	Albite-rich granophyre	5375340N, 378615E
54636	Quartz-feldspar-phyric lava/intrusive	5375330N, 377945E
54664	Granophyre	5373065N, 379850E
54697	Silicified, spherulitic lava	5375935N, 378555E
54728	Basalt lava	5372600N, 380220E

54729	Amygdaloidal basalt	5372600N, 380250E
54793	Quartz-feldspar-phyric tuff	5376800N, 377550E
54866	Welded feldspar-phyric tuff	5371980N, 378130E
54887	Pyritic quartz-chlorite rock	5370770N, 378330E
54911	Quartz-amygdaloidal (?) lava/intrusive	5370310N, 378330E
54939	Spherulitic rhyolite lava	5375450N, 379060E
54945	Granophyre	5375670N, 379275E
54947	Granophyre	5375795N, 379450E
55020	Packed carbonate spheroids	5374690N, 378610E
55028	Andesite lava	5371355N, 380090E
55040	Lithic sandstone	5374700N, 378650E
55042	Flow-banded rhyolite lava	5371600N, 380180E
55051	Quartz-tourmalinite	5371500N, 378945E
55079	Silicified quartz-feldspar-phyric tuff	5370820N, 377660E
55155	Silicified tuff or lava with gn-sp stockwork	5372230N, 379310E
55277	Nodular carbonate in lithic tuff	5366660N, 376610E
55280	Pumiceous feldspar-phyric tuff	5367030N, 376705E
55281	Pumiceous feldspar-phyric tuff	5367105N, 376730E
55285	Altered pumiceous feldspar-phyric tuff	5367285N, 376538E
55301	Weakly mineralized psammitic ash tuff	5366595N, 376610E
55320	Ash tuff	5366590N, 376665E
55349	Carbonate pods in altered tuff	5366100N, 376580E
55351	Strongly silicified, sericitized tuff	5366085N, 376520E
55360	Silicified vitric tuff	5366405N, 376475E
55416	Quartz-phyric intrusive	5366345N, 377940E
55417	Quartz-phyric lava / intrusive	5366015N, 377985E
55421	Lava-breccia	5366910N, 377725E
55425	Basaltic lava	5367179N, 377630E
55431	Chloritized reworked tuff	5367930N, 377590E
55449	Pelitic ash / siltstone	5366575N, 376475E
55457	Pumiceous feldspar-phyric tuff	5367070N, 375940E
55461	Quartz-feldspar-phyric tuff	5365800N, 376700E
55464	Lithic sandstone	5366475N, 376200E
55473	Quartz-feldspar-phyric tuff	5365350N, 376800E
55481	Vitric tuff	5367255N, 377215E
55500	Pelitic ash / vitric tuff	5365685N, 376855E
55504	Pelitic ash	5365330N, 376980E

55508	Pelitic ash	5365115N, 376220E
55513	Welded feldspar-phyric tuff	5365020N, 376955E
55520	Pelitic ash	5365375N, 376895E
55525	Altered pumiceous feldspar-phyric tuff	5366940N, 376450E
55547	Volcanogenic lithic wacke	5364460N, 375490E
55563	Sheared quartz-feldspar-phyric lithic tuff	5369725N, 378485E
55566	Spherulitic dacite lava	5370405N, 379053E
55567	Granophyre	5370150N, 379135E
55570	Amygdaloidal andesitic lava	5377195N, 378480E
55571	Sheared andesitic lava	5370173N, 379092E
55572	Quartz-feldspar-phyric tuff	5377777N, 378310E
55573	Quartz-feldspar-phyric tuff	5377635N, 377530E
55584	Amygdaloidal flow-brecciated lava	5377635N, 377940E
55606	Massive sulphides	5365105N, 376565E
55743	Amygdaloidal lava / intrusive	5371395N, 377705E
55744	Amygdaloidal lava / intrusive	5371400N, 377720E
55748	Sericitized vitric tuff	5367980N, 376360E
55749	Vitric tuff	5367975N, 376370E
55770	Gabbro	5367240N, 375185E
56089	Bedded epiclastic tuff	5374035N, 380030E
56094	Flow-brecciated rhyodacite lava	5366515N, 378830E
RFW 7M 7N	Sphalerite in chlorite-sericite schist	R lode Hercules 7M 7N
R 1121 550'	Welded(?) feldspar-phyric tuff	
R 2971 77'	Magnetite-biotite-tourmaline rock	
R 3016 225'	Pyrrhotite-biotite-tourmaline rock	
H 704 244'	Dacitic lava	
375'	Dacitic lava	
894'	Lithic tuff	
H 955 350'	Feldspar-phyric tuff	
530'	Feldspar-phyric tuff	
1016'	Feldspar-phyric tuff	
1302'	Feldspar-phyric tuff	
H 1106 28.5m	Silicified tuff with pyrite, arsenopyrite, sphalerite, jamesonite	
73 R 170.3m	Hyaloclastic dacite lava	
252.8m	Quartz-feldspar-phyric tuff	
441.3m	Quartz-phyric crystal-rich tuff	
457.3m	Silicified perlitic lava	

	470.3m	Chloritized perlitic lava
	517.7m	Altered vitric tuff
	554.6m	Altered vitric tuff
	583.3m	Quartz-phyric lava
	640.2m	Quartz-phlogopite-altered feldspar-phyric tuff
KP 196	206'	Pyritized, silicified tuff
	411'	Brecciated lava or ash tuff
	519'	Feldspar-phyric tuff
KP 197	95'	Sericitized vitric tuff
	177'	Spherulitic lava or pyritized, silicified tuff
	191'	Pyritized, silicified tuff
	357'	Spherulitic lava or pyritized, silicified tuff
	412'	Spherulitic lava or pyritized, silicified tuff
KP 198	34'	Pumiceous vitric tuff
	83'	Pumiceous vitric tuff
	193'	Spherulitic lava or pyritized, silicified tuff
	283'	Amygdaloidal dacitic lava
	299'	Veined, altered vitric tuff
KP 201	35'	Vitric tuff
DP 259	43.5m	Rhyolite lava
	128.7m	Sheared dacite lava
	141.3m	Autobrecciated dacite lava
	161.5m	Limestone
	180.2m	Hematite-talc-altered limestone
DP 265	230.8m	Quartz-feldspar-phyric tuff
	250.8m	Quartz-feldspar-phyric tuff
	318.1m	Quartz-feldspar-phyric tuff, magnetite veined
	341.1m	Quartz-feldspar-phyric tuff
BD 269	44.3m	Brecciated pelitic ash
	188.8m	Quartz-feldspar-phyric tuff
	227.3m	Brecciated shale
	268.4m	Quartz-feldspar-phyric tuff
LB 270	194.9m	Welded feldspar-phyric tuff
LB 271	130.5m	Welded feldspar-phyric tuff
RLP 274	43.3m	Dacite lava
	67.0m	Quartz-feldspar-phyric tuff
RLP 275	88.8m	Dacite lava